TOTAL THICKNESS AND COMPACTION REQUIREMENTS FOR FLEXIBLE PAVEMENTS TO BE SUBJECTED TO CHANNELIZED TRAFFIC

TECHNICAL REPORT NO. 3-610

November 1962

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. TOTAL THICKNESS AND COMPACTION REQUIREMENTS FOR FLEXIBLE PAVEMENTS TO BE SUBJECTED TO CHANNELIZED TRAFFIC, by C. D. Burns, November 1962, vii, 27 pp - illus - tables. (Technical Report No. 3-610)

Unclassified report

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ARMY-MRC VICKSBURG, MISS.

PREFACE

The investigation reported herein was authorized in a memorandum, dated 28 July 1955, from Headquarters, U. S. Air Force, to the Office, Chief of Engineers, subject, "Accelerated Traffic Test for the Development of Pavement Design Criteria for Channelized Traffic."

The study was conducted by the Flexible Pavement Branch, U. S. Army Engineer Waterways Experiment Station.

Engineers of the Waterways Experiment Station actively concerned with the planning, testing, analysis, and report phases of the study were Messrs. W. J. Turnbull, C. R. Foster, A. A. Maxwell, O. B. Ray, C. D. Burns, and A. A. Joseph. This report was prepared by Mr. Burns.

Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE, were Directors of the Waterways Experiment Station during the preparation of this report. Mr. J. B. Tiffany was Technical Director.

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SUMMARY

In 1955, pavement distress at certain air bases caused by channelized traffic of heavy (B-47) aircraft prompted modifications to the existing design criteria for flexible pavements, including increases in: total thickness above subgrade, subgrade compaction requirements, and base course thickness. In order to validate the revised criteria, a program of laboratory and traffic tests was initiated. A test section was designed, constructed, and tested to determine whether the increase in total thickness and the increase in subgrade compaction requirements for cohesionless materials were needed. One part of the test section consisted of a clay subgrade 24 in. thick with a CBR of 10, overlaid with three different thicknesses of subbase and with 13 in. of base and pavement. The other part of the test section consisted of sand subgrade 96 in. thick with a CBR of 25, overlaid by the current design thicknesses of base and pavement. The bottom 6 ft of sand was placed in a loose state; the top 2 ft was compacted to a dense state. Three traffic test phases were conducted in which the number of coverages, weight of test load, tire pressure, and total thickness were varied.

Laboratory and traffic test results indicated that for areas of channelized traffic: (a) the increase in total thickness as specified in the interim design criteria is not needed; and (b) the revised or current compaction requirements for cohesionless soils are adequate for a deep sand subgrade for depths below about 3 ft from surface of pavement, but any cohesionless material above the 3-ft depth should be compacted to the highest practicable density.

It is recommended that: (a) additional tests be made on lower (CBR of about 3 to 5) and higher (CBR of about 20) strength subgrades before modifying the current CBR design curves; (b) additional data showing the relation of percentage of design thickness to number of coverages be collected; and (c) research in methods and procedures of soil compaction be continued.

TOTAL THICKNESS AND COMPACTION REQUIREMENTS FOR FLEXIBLE PAVEMENTS TO BE SUBJECTED TO CHANNELIZED TRAFFIC

PART I: INTRODUCTION

1. Early in 1955 pavement distress was reported at 6 of 10 air bases where B-47 aircraft were operating on flexible pavements. Traffic distribution studies conducted at this time showed that the B-47 aircraft were operated in narrow channelized lanes on taxiways, resulting in the application of traffic coverages (load repetitions) at about six times the rate of earlier-type aircraft of similar size. In view of the intensity of the B-47 traffic and the resultant pavement distress, it was considered necessary to modify certain aspects of the existing pavement design criteria to accommodate the greater number of load repetitions. Accordingly, Interim Design Criteria for Airfield Pavements to be Subjected to Channelized Traffic of Heavy Aircraft, issued by the Office, Chief of Engineers, on 15 June 1955, provided for increases in:

- a. Total thickness
- b. Subgrade compaction requirements
- c. Base course thickness

The revised criteria also required proof-rolling with a heavy rubber-tired roller at the top of the subbase and on each layer of base course material. In addition to the above-listed modifications, the Guide Specifications were revised to require the use of higher quality materials in bases, subbases, and asphalt paving mixtures.

2. At the time the interim criteria were published, a rather comprehensive program of laboratory and traffic tests was initiated at the U. S. Army Engineer Waterways Experiment Station to validate the revised criteria. As a part of this program a traffic test section was designed, constructed, and tested to determine (a) whether the increase in total thickness was needed, and (b) if the increased compaction requirements were adequate for a cohesionless sand subgrade. The results of this investigation are presented herein.

PART II: TEST SECTION

Design

Items 1, 2, and 3

3. A plan and profile of the test section are shown in fig. 1. Items 1, 2, and 3 of the test section were designed to study total thickness requirements over a clay subgrade with a CBR of 10. The clay subgrade was to be constructed to a thickness of 24 in. and overlaid with a subbase of three different thicknesses and with 13 in. of base and pavement. The 13 in. of base and pavement would normally consist of 8 in. of base and 5 in. of asphaltic concrete. However, in order to eliminate temperature as a factor influencing the behavior of the structure under traffic, the 5-in. thickness of asphaltic concrete was omitted and 12 in. of base plus a 1-in. double surface treatment was substituted for the 13 in. of base and pavement. Thus traffic-testing could be performed at lower temperatures than would be desirable if a 5-in. asphaltic concrete surface were used. The total thicknesses above subgrade for items 1, 2, and 3 were 42, 35, and 28 in., respectively, which represent 120, 100, and 80 percent, respectively, of the thickness required over a subgrade of 10 CBR by the interim design criteria for channelized traffic of B-47 aircraft (100,000-lb twin-wheel gear load).

Item 4

4. Test item 4 was designed to study compaction requirements for a deep sand subgrade. The sand was to be placed to a depth of 96 in. and overlaid by the proper design thicknesses of base and pavement. The lower 6 ft of sand was to be placed in as loose a state as possible and the upper 2 ft compacted to as high a density as possible. It was assumed that the ultimate density which would develop under traffic would indicate the proper compaction requirements, and that the percentage of modified density developed in the sand would be applicable to any cohesionless material. The sand subgrade was assigned a design CBR value of 25, which required a total thickness of 15 in. above the subgrade. This was provided by 14 in. of base course plus 1 in. of double surface treatment.

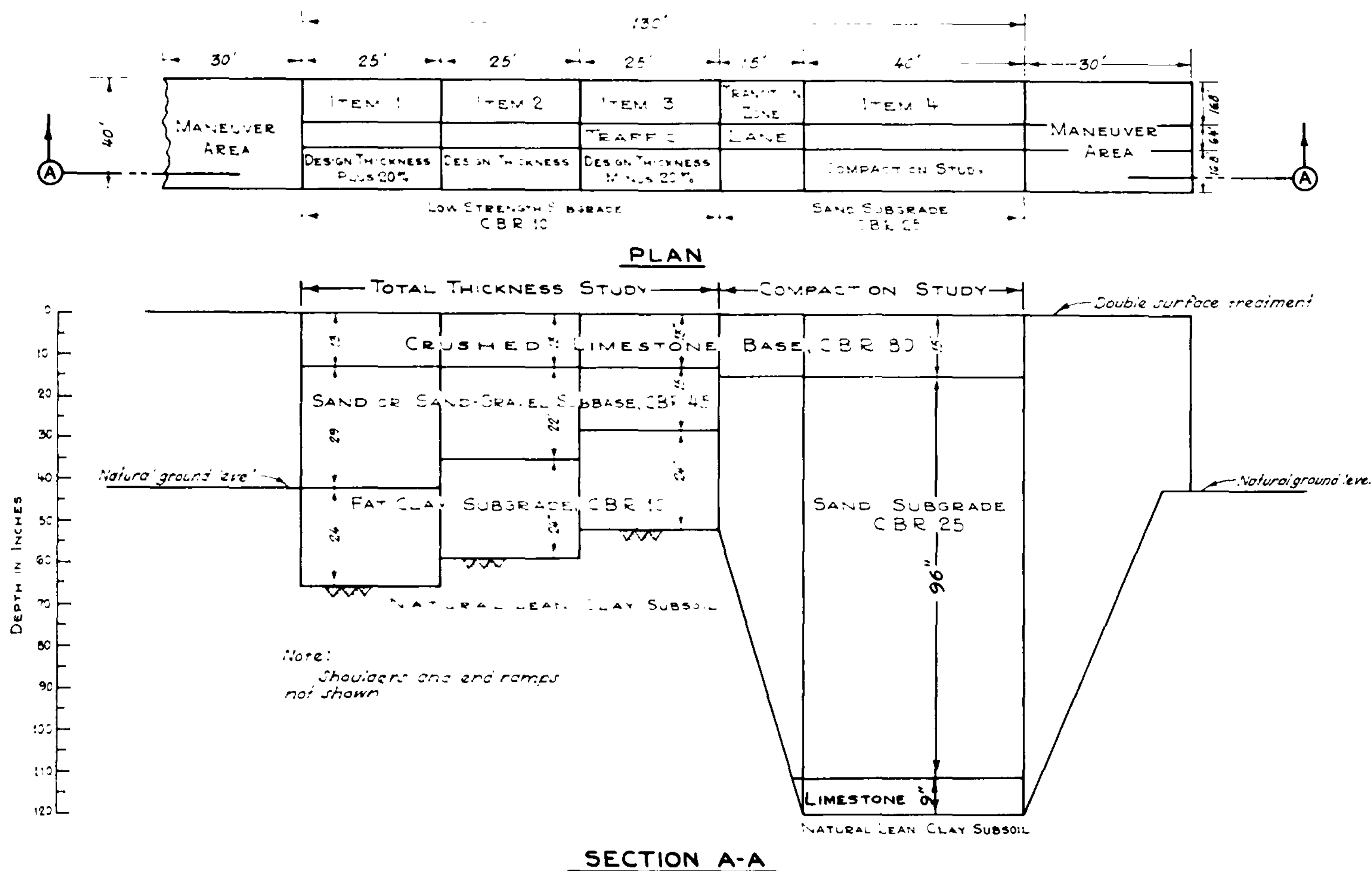


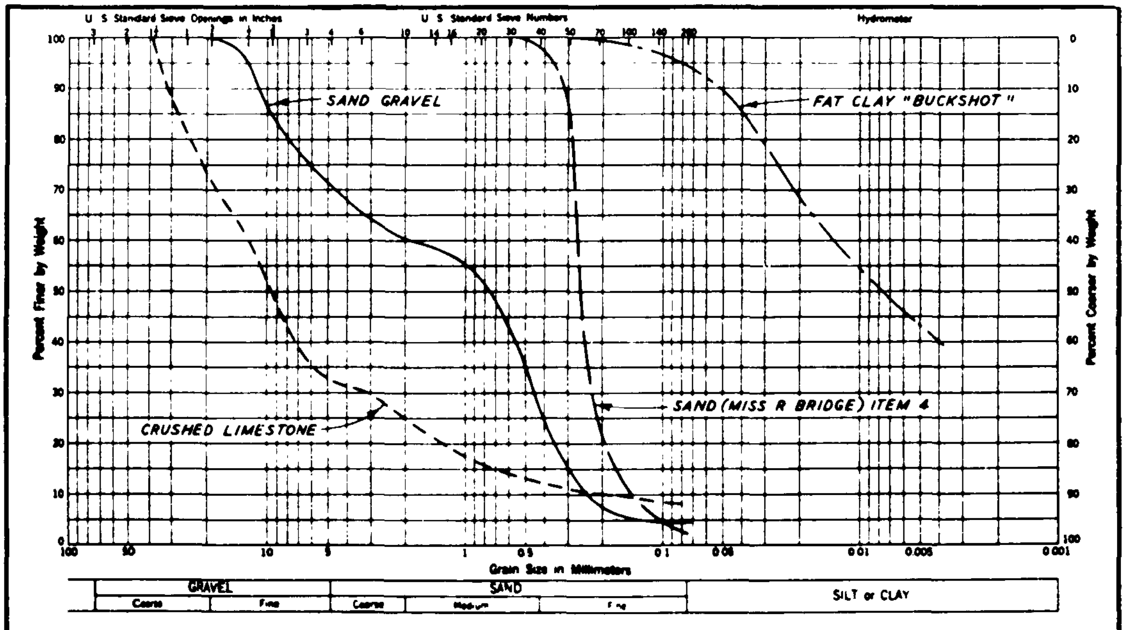
Fig. 1. Plan and profile of test section

Construction

5. The test section was built inside a shelter in order to permit construction and traffic-testing during adverse weather and to more accurately control the strength of the subgrade. Construction was accomplished in accordance with plan and section of fig. 1 during the period 5 September to 5 December 1955.

Materials

6. Classification data for the materials used in the test section are shown in fig. 2, and laboratory compaction data are shown in figs. 3 and 4. The crushed limestone used as the base course was obtained from



Number	Depth	Natural Moisture	LL	PL	PI	Classification
1	BASE	—	—	—	—	CRUSHED LIMESTONE - GW - GM
2	SUBBASE	—	—	—	—	SAND GRAVEL - SP
3	SUBGRADE	—	—	—	—	SAND - SP
4	SUBGRADE		55	22	33	FAT CLAY - BUCKSHOT - CH

Fig. 2. Gradation and classification of materials used in test section

a quarry near Nashville, Tenn., and was graded and blended to meet all requirements of current specifications for a crushed aggregate base course. The sand gravel used as the subbase for items 1, 2, and 3 was a pit-run creek gravel (oversize stones crushed) obtained locally. A fat clay, known locally as "buckshot," was used for the subgrade in items 1, 2,

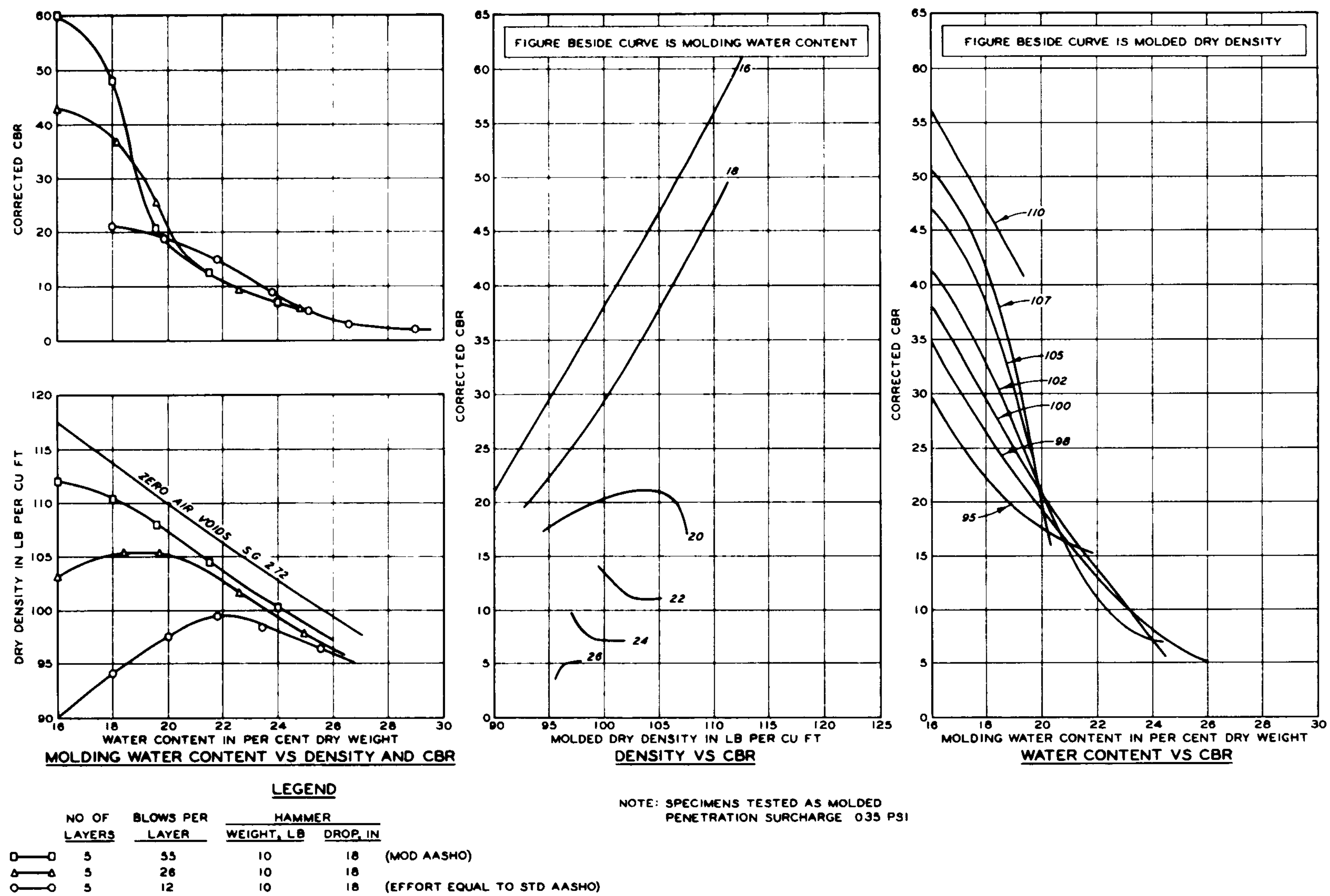


Fig. 3. CBR, density, and water-content data for clay subgrade, items 1, 2, and 3

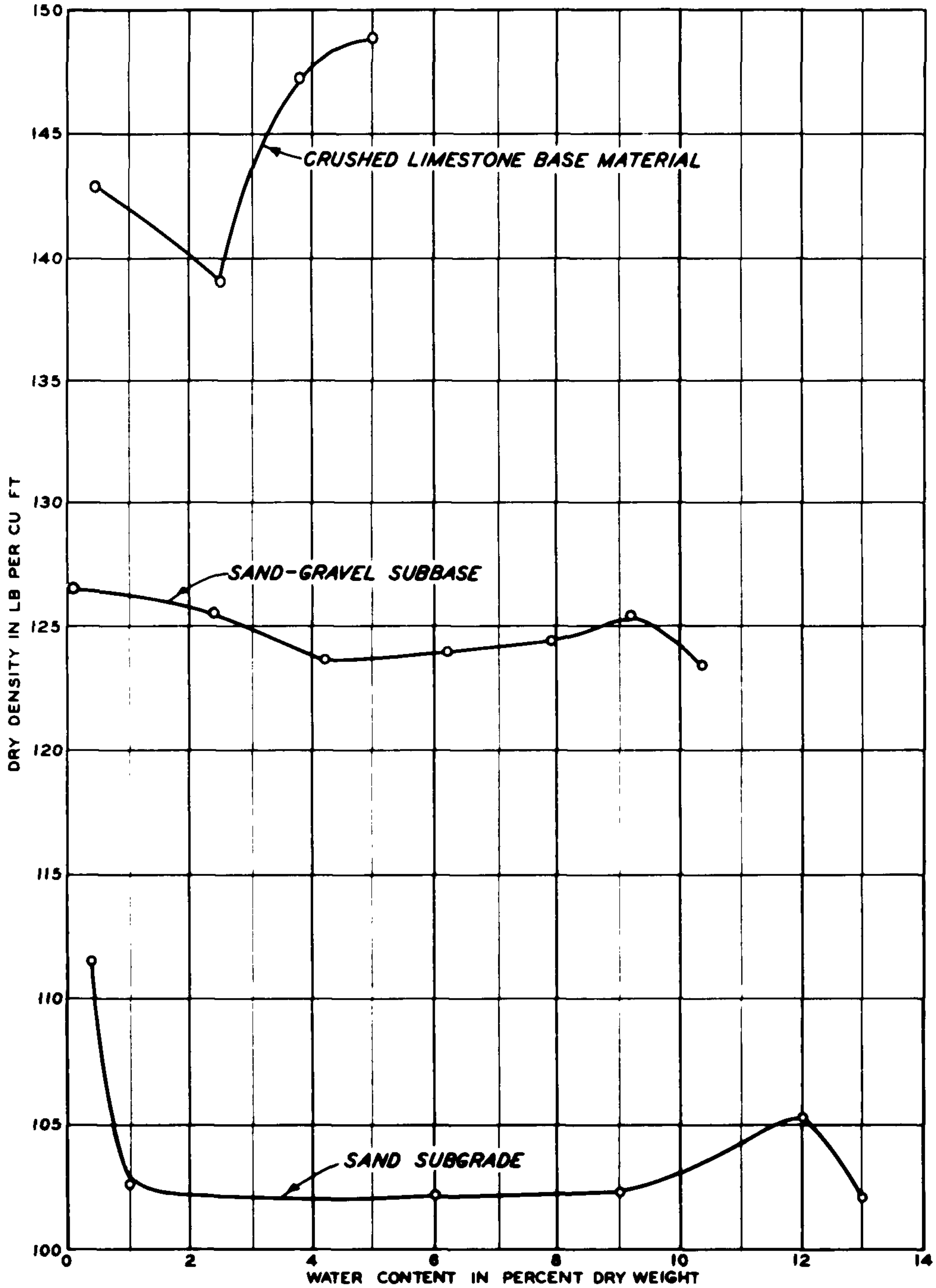


Fig. 4. Laboratory compaction data for materials used in test section

and 3. This clay is typical of the heavy clays found in the alluvial valley of the Mississippi River. The sand used in item 4 was obtained from a sandbar along the Mississippi River near Vicksburg, Miss. It was a

uniform, fine sand with a grading typical of many of the sand deposits found throughout the southeastern United States.

Procedure

7. The natural lean clay soil at the test site was excavated to the depths shown in fig. 1. The variation in depth of excavation for the various test items was necessary in order to obtain the desired thickness of subgrade and thickness above the subgrade. The methods used in placing and compacting the various materials in the test section are presented in the following paragraphs.

8. Fat clay subgrade. This material was placed in items 1, 2, and 3 to the required 2-ft depth in four lifts, each 6 in. deep. Each lift was compacted by 10 coverages of a rubber-tired roller weighing 50,000 lb with tires inflated to 90 psi. Soil tests following construction of this subgrade indicated that the clay was placed at a water content ranging from 19.8 to 21.6 percent and had developed an average density of 101.8 to 103.9 lb per cu ft. The average in-place CBR strength of the subgrade approximated the design CBR of 10. The surface of the clay subgrade was sealed with asphalt cement to retain the as-constructed water content, as shown in fig. 5.

Fig. 5. Surface of clay subgrade sealed with asphalt cement

9. Sand subgrade. Prior to placement of the sand subgrade of item 4, 9 in. of coarse crushed limestone was placed in the bottom of the

excavation. A drainage pipe (fig. 6) leading to a sump located 100 ft from the test section was installed to carry off any free water that might collect in the sand subgrade during construction of the base course. In order

Fig. 6. Drainage pipe installed in sand subgrade of item 4

that the lower 6 ft of sand would be as loose as practicable, it was placed at the water content indicated by the laboratory compaction curves as that which would develop the lowest density. The sand was spread in 1-ft lifts at a "bulking" moisture content of 3 percent. Each lift was compacted by eight coverages of a D7 dozer to an average density of 94.4 lb per cu ft (lower 6 ft). A uniform density was quite difficult to achieve in the loose sand, particularly in the central portion of the test section where settlement plates (with their pipes leading to the surface of the subgrade) were installed at 1-ft increments in elevation. (The settlement plate installation is discussed, with pertinent observations, subsequently in this report.) A high density was desired in the upper 2 ft of sand directly under the base course. The laboratory compaction curve (fig. 4) shows that high densities developed in both dry and wet sand. The highest laboratory density was actually obtained on dry sand (0.3 percent water content), but since in actual construction work it is not practical to dry sand prior to compaction, the peak density of 105.3 lb per cu ft at 12 percent water content was considered as modified AASHO maximum density.

However, in the test section water from a saturated surface layer of sand would have drained into the lower levels of the subgrade and caused increases in density during construction; therefore, the required high density in the upper 2 ft of subgrade was achieved by using sand which had been dried in an aggregate dryer. This upper 2 ft of dried sand was placed in 6-in. lifts which were thoroughly compacted by a D7 dozer to an average density of 105.1 lb per cu ft. Water contents and densities were determined during construction as each lift of the fill was completed. These values are tabulated below.

Depth Below Surface of Sand Subgrade, in.	Average Density lb/cu ft	Percent Modified AASHO Density	Average Water Content, %
2.0	104.4	99	0.3
8.0	104.8	100	0.1
14.0	105.0	100	0.2
20.0	106.1	101	0.2
24.8	92.6	88	3.1
36.8	92.2	87	3.4
48.8	94.0	89	2.8
60.8	95.2	90	2.9
72.8	95.9	91	3.0
84.8	94.0	89	2.9

It is probable that actual density of the lower 6 ft of sand was slightly greater than the values recorded in this tabulation since placement and compaction of subsequent lifts would tend to compact the lower sand layers. Settlement plate readings during construction gave some indication that densities in the lower depths increased slightly during construction. However, disturbance of the settlement plates during construction prevented an exact estimate of a change in density as a result of compaction of subsequent lifts of the fill.

10. Sand-gravel subbase. This material was placed in items 1, 2, and 3 in lifts about 4 in. thick to the required thicknesses of 29, 22, and 15 in., respectively. Prior to placement of the sand-gravel material, a layer of crushed limestone was placed along each shoulder to permit drainage and to provide lateral confinement for the cohesionless subbase material. The first lift of the sand gravel in item 1 was placed at a water content of 9 percent, using a truck and spreader box. An attempt to compact the material with a heavy rubber-tired roller was unsuccessful as the

sand gravel did not prove to be a free-draining material; it rutted and displaced under the rubber tires and became spongy. Final compaction of the first lift was accomplished with a D7 dozer. Each of the subsequent lifts of sand gravel was placed at a water content of about 4 percent with a paver serving as a mechanical spreader, and was compacted by eight coverages of a D7 dozer. Control tests taken as each lift was completed indicated that water contents averaged 3.0 to 3.4 percent and densities averaged 129.7 lb per cu ft.

11. Crushed limestone base. The limestone base material was placed with a paving machine in four lifts, each having a compacted thickness of about 3 in. which resulted in the desired 12-in. thickness for items 1, 2, and 3. An additional lift was required in item 4 to provide for the greater thickness of base specified in the design. The material was placed in a rather wet state, and additional water was added during compaction rolling to maintain the material in essentially a saturated condition. Compaction was accomplished with a 50-ton rubber-tired roller with tires inflated to 150 psi. A three-wheel, steel, tandem roller was used along with the rubber-tired roller to maintain a level surface. The first lift of base course was compacted by 28 coverages of the rubber-tired roller loaded to 50,000 lb. This light load was used to preclude excessive shifting and rutting over the sand subgrade and sand-gravel subbase. Each successive lift was compacted by 30 coverages of the roller loaded to 100,000 lb. An additional 30 coverages of proof-rolling were applied on the top lift with the roller loaded to 120,000 lb. This rolling produced an average dry density of about 154 lb per cu ft in the base course material, which is about 104 percent of modified AASHO maximum density.

12. Each layer of compacted base course was allowed to cure for a period of four days prior to placement of the next lift. The final lift was allowed to cure for 11 days prior to the double surface treatment.

13. Double surface treatment. The surface of the crushed limestone base was first swept with a wire broom and then primed with RC-2 asphalt at the rate of 0.15 gal per sq yd. The prime had to be blotted in spots since the dense base did not permit the expected degree of penetration. The double surface treatment consisted of asphalt cement (80 penetration) placed at a working temperature of 275 to 300 F at an application rate of

0.4 gal per sq yd for the first coat and 0.3 gal per sq yd for the second coat. Limestone chips (3/4-in. maximum size) were spread at the rate of 35 lb per sq yd for the first coat; for the second coat, smaller limestone chips (3/8-in. maximum size) were spread at the rate of 25 lb per sq yd. The double surface treatment was compacted by 20 coverages of a wobble-wheel roller loaded to 10,000 lb and 10 coverages of a tracking rig with 25,000-lb wheel load and 200-psi tire inflation pressure. Fig. 7 shows the completed test section before traffic.

Fig. 7. Test section before traffic

Instrumentation

Deflection gages

14. In order to measure vertical deflections during traffic-testing, Selsyn motor deflection gages were installed at the surface of both the sand-gravel subbase and the fat clay subgrade in items 1, 2, and 3 (see fig. 8). No deflection gages were installed in item 4. These gages were carefully placed and checked to ensure that they were working properly

Fig. 8. Selsyn motor deflection gage installed at surface of the subbase

Fig. 9. Settlement plates

before additional fill material was placed. The three gages at the surface of the subbase were installed after the first lift of the limestone base had been spread and compacted. The fill immediately above and beside the gages was placed and compacted by hand.

Settlement plates

15. Sixteen settlement plates, such as shown in fig. 9, were placed at eight elevations in the sand subgrade of item 4. Two plates each were located at the surface of the subgrade and at about 1-ft increments to a total depth of 7 ft. Due to difficulties in placing and compacting the sand fill around the pipes, five of the plates were destroyed during construction. The two rows of pipes leading from the settlement plates were 3 ft apart. The traffic lane was to be centered over these two rows of plates so that deformations measured at any plate

would be comparable, as each plate was located at the same lateral offset from the center line of the traffic lane. The plate elevations were determined to the nearest 0.01 ft on a level rod which had been lowered inside the hollow iron pipe leading from each plate to the surface of the subgrade. Fig. 10 shows item 4 with the settlement plates installed after 6 ft of the 8-ft sand fill had been placed.

Fig. 10. Settlement plates installed in the sand subgrade of item 4

Evaluation of As-Constructed Section

16. At the completion of construction, test pits were excavated in each item of the test section and in-place CBR, density, and water-content determinations were made in each element of the structure, i.e. base, subbase, and subgrade. The results of these tests are summarized in table 1 and identified as before-traffic data. These data show that the base course was highly compacted to about 105 percent of modified AASHO maximum density, which resulted in an in-place CBR of above 200. The sand-gravel subbase used in items 1, 2, and 3 was also highly compacted, its density ranging from 133 to 137 lb per cu ft (106 to 109 percent of modified AASHO

maximum). These are considerably higher densities than were indicated by the construction-control data taken in the sand gravel; the average density measured during construction was 129.7 lb per cu ft. This increase in density occurred during construction of the crushed-aggregate base course. The in-place CBR of the sand gravel varied from 57 to 76 as shown in table 1. There was little or no change in the water content or density of the clay subgrade from the values determined during construction. However, the CBR values were slightly higher than desired. The in-place CBR's of the clay subgrade were 12, 11, and 11 for items 1, 2, and 3, respectively. Tests made at the top of the sand subgrade in item 4 showed an average dry density of 104.4 lb per cu ft at 3.6 percent water content and an in-place CBR of 38. This indicated no change in density due to placement of the base course. However, the water content increased from 0.3 (see paragraph 9) to 3.6 percent, because of moisture draining into the sand from the base course.

17. Since the as-constructed CBR of the clay subgrade was higher than the design value of 10, the percentage of design thickness was slightly greater than desired as indicated below:

	Item 1	Item 2	Item 3
Design			
CBR	10	10	10
Total thickness above subgrade, in.	42	35	28
Percentage of design thickness	120	100	80
As-constructed			
CBR	12	11	11
Percentage of design thickness	131	106	85

PART III: TRAFFIC TESTS AND RESULTS

Traffic Tests

Test program

18. It was originally planned to apply 30,000 coverages of traffic to the test section with a 100,000-lb twin-wheel assembly load with tires inflated to 200 psi, thus simulating the channelized traffic of a fully loaded B-47 aircraft. However, as traffic-testing progressed, two modifications were made in test plans: the first involved an increase in load to 150,000 lb and an increase in tire pressure to 300 psi; and the second involved a reduction of 3 in. in the test section's total thickness for items 1, 2, and 3. For report purposes the traffic-testing will be considered in three phases: phase 1, the traffic applied prior to any modification, and phases 2 and 3, that applied after the first and second modifications, respectively. The traffic applied during each phase was as follows:

- a. Phase 1 consisted of 9142 coverages of traffic with 100,000-lb twin-wheel assembly load, 200-psi tire pressure, applied during the period 5 December 1955 through 16 January 1956.
- b. Phase 2 consisted of 10,496 coverages of traffic with 150,000-lb twin-wheel assembly load, 300-psi tire pressure, applied during the period 7 February through 4 April 1956.
- c. Phase 3 consisted of 7186 coverages of traffic with 150,000-lb twin-wheel assembly load, 300-psi tire pressure, applied during the period 5 December 1956 through 9 January 1957, after a 3-in. reduction in total thickness of test items 1, 2, and 3.

Test load cart

19. Traffic was applied with a test load cart (see fig. 11) powered by a Model C Tournapull. The load cart consisted of a load box supported by an A-frame, and a twin-wheel assembly consisting of an axle with two 24-ply, 56- by 16-in. tires spaced 36 in. c-c (as on B-47 aircraft). Two load boxes were operated in tandem during phase 1 traffic. This arrangement resulted in a bicycle-gear configuration with the twin assemblies approximately 27 ft apart. (The actual spacing on a B-47 aircraft is 36 ft.) For the heavier loads used in phases 2 and 3, only one load box was used.

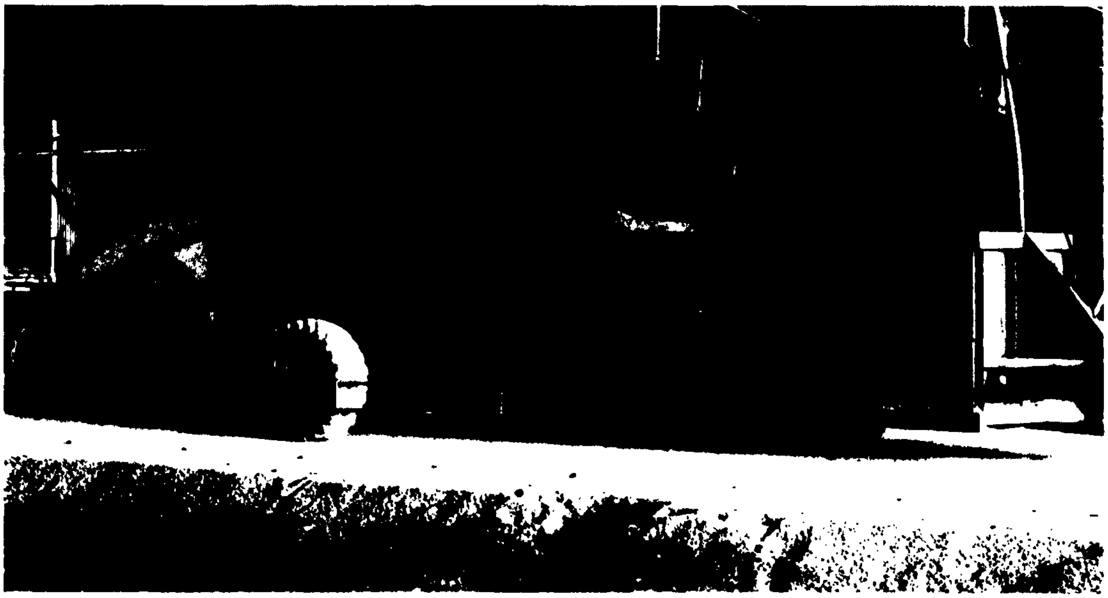


Fig. 11. Traffic test load cart

Traffic pattern

20. Traffic was applied uniformly over a traffic lane 7.3 ft wide. The load cart was operated forward and backward for the length of the traffic lane and shifted laterally on each forward pass to obtain uniform coverages.

Observations and data obtained

21. Visual observations of the behavior of the various test items were made throughout the period of traffic. In-place CBR, density, and water-content determinations were made in each element of the various test items prior to traffic and at the end of each phase of traffic-testing. In addition, deflection measurements (elastic deflection under load) and permanent deformation (settlement) were determined at various intervals of traffic at the surface of subbase and subgrade in items 1, 2, and 3. These determinations were made from readings obtained from the Selsyn motor deflection gages installed during construction. Permanent deformation at the surface of each test item was determined from level readings taken at various intervals of traffic. The elevation of the settlement plates in the deep sand subgrade was also determined prior to traffic and at the end of each phase of traffic. These observations were supplemented by photographs taken throughout the testing program.

Test Results

Phase 1

22. The application of 9142 coverages of traffic with the 100,000-lb twin-wheel assembly load with tire pressure of 200 psi caused no distress in any of the test items. Plots of deformation versus coverages for items 1, 2, and 3 are shown in plate 1. These data indicate elastic deflection under load and the cumulative permanent deformation as measured by the deflection gages at top of subbase and top of subgrade. Also shown is the average permanent deformation (or settlement) at the surface of pavement. From these data it can be noted that the deflection under load was relatively low in all three test items. The greatest deflection, 0.14 in., was measured at top of subbase in test item 3 at about 40 coverages of traffic. The pattern of the deflection versus coverage curves is similar for all test items; i.e., a slight increase in deflection occurred with the first few coverages of traffic, then with continued load repetitions the deflection decreased. Generally, the maximum deflection occurred at less than 100 coverages. This indicated that the pavement structure was gaining strength with increased load repetitions. Also there was a consistent increase in the cumulative permanent deformation throughout the period of traffic. Most of this deformation was due to densification of the various materials. However, part of the permanent deformation indicated at the surface of the pavement was due to abrasion and loss of material at the surface.

23. A plot of coverages versus surface deformation for test item 4 shows that approximately 1.2 in. of settlement occurred in the deep sand subgrade section as a result of 9142 coverages of traffic (see plate 2). Readings from the settlement plates indicated that nearly all this settlement occurred in the sand subgrade.

24. The general condition of items 1 through 4 was very good at the end of 9142 coverages of traffic with the 100,000-lb gear load (see photographs 1 through 4, respectively). At this stage of traffic, test pits were excavated in each test item and in-place CBR, water-content, and density determinations were made in the various elements of the structure. The results of these tests are included in table 1. These data show that

the traffic resulted in an increase in density in the limestone base material in all four test items. There was also an increase in CBR from the as-constructed values in all elements of each test item. However, the increase in CBR of the clay subgrade was relatively small. From this increase in strength together with the low deflections that were occurring under traffic, it was evident that failure would not be produced by continued traffic of the 100,000-lb gear load and 200-psi tire pressure.

25. An evaluation of the percentage of design thickness for test items 1, 2, and 3 at the end of phase 1 traffic was as follows:

	Item 1	Item 2	Item 3
Total thickness, in.	42	35	28
Subgrade CBR (end phase 1)	13	13	12
Design thickness (150,000-lb load), in.*	39	39	41
Percentage of design thickness	108	90	68

* From fig. 11 of EM 1110-45-302, Engineering and Design, Flexible Airfield Pavements, Air Force, 15 August 1958.

Phase 2

26. In order to establish a more severe loading condition for further testing, a series of deflection measurements was made in items 1, 2, and 3 under a range of assembly loads up to 150,000 lb. The results of these measurements show a fairly constant increase in deflection with increase in load up to 140,000 lb and a rather sharp increase in deflection between 140,000 and 150,000 lb (plate 3). The maximum deflection measured under the 150,000-lb load was 0.17 in. at top of subbase in item 3. It was believed that this deflection was approaching a critical state and that traffic with the 150,000-lb twin-wheel load would probably produce failure in item 3. Therefore, for phase 2 traffic the load was increased to 150,000 lb and the tire pressure was increased to 300 psi to maintain a constant contact area of 267 sq in.

27. Traffic with the 150,000-lb gear assembly caused no visual distress in test items 1 and 2. However, some cracking developed in test items 3 and 4, and noticeable settlement occurred in item 4. The first crack was observed in test item 3 at about 400 coverages. This was a hairline transverse crack about 3 ft long which developed across the traffic lane. As traffic continued, the crack became more pronounced and several

other cracks developed. One of the cracks at the end of 4000 coverages of traffic is shown in photograph 5; this crack extended fairly deep into the base course. Intermittent longitudinal tension cracks also developed about 18 in. outside the traffic lane, parallel to direction of traffic, in test item 4. These cracks were on each side of the traffic lane, and were first observed at about 400 coverages. By 4000 coverages they were quite pronounced, as shown in photograph 6. By 4572 coverages of traffic, the surface of the pavement had become slightly rough due to abrasion, and it was thought that the occasional pieces of protruding aggregate might be a contributing factor to the frequent tire failures that were occurring. Also, the settlement in item 4 was quite severe with an average deformation in the traffic lane of about 2 in. To correct this condition, a leveling course of crushed-stone base material was applied over item 4, and a layer of sand asphalt about 1/2 in. thick was applied over the entire traffic lane. The sand asphalt was slightly rich and remained soft and pliable throughout the remaining period of traffic. Phase 2 traffic was continued up to a total of 10,496 coverages. During this period the cracks which were observed earlier in item 3 did not show through the sand-asphalt surface. Items 1 through 4 at the end of 10,496 coverages are shown in photographs 7 through 10.

28. Plots of coverages versus deformation for items 1, 2, and 3, phase 2 traffic, are shown in plate 4. These data show about the same trends as the deflection data obtained during phase 1 traffic, the main difference being slightly higher deflections under the heavier load.

29. In-place CBR, water-content, and density data taken at end of 10,496 coverages showed no significant change in the overall strength of the pavement structure in any of the test items (see table 1). This fact along with visual observations of behavior and deflection data indicated that failure would not be produced by further traffic on the existing test section with the 150,000-lb gear load. Therefore, it was decided to reduce the total thickness over items 1, 2, and 3 by 3 in., and then continue traffic with the 150,000-lb gear load.

<u>Phase 3</u>

30. In preparation for phase 3, the sand-asphalt layer and about 3 in. of base were removed from items 1, 2, and 3, and a new sand-asphalt

surface was applied. The total thickness over item 4 was not changed. After the 3-in. reduction in total thickness, the percentages of design thickness for items 1, 2, and 3 were as follows:

	Item 1	Item 2	Item 3
Total thickness, in.	39	32	25
Subgrade CBR (end phase 2)	14	13	12
Design thickness (150,000-lb load), in.*	37	39	41
Percentage of design thickness	105	82	61

* From fig. 11 of EM 1110-45-302, Engineering and Design, Flexible Airfield Pavements, Air Force, 15 August 1958.

31. A total of 7186 coverages of traffic with the 150,000-lb twin-wheel load were applied during phase 3. Test items 1 and 2 performed satisfactorily throughout this period of traffic. Item 3 was considered a borderline case due to cracking which developed during the early stages of this phase. The first crack in item 3 appeared at about 1300 coverages of traffic and by 5000 coverages, four cracks extended across the traffic lane. One of the cracks at the end of 5743 coverages is shown in photograph 11. There was no apparent change in the extent of cracking between 5000 and 7186 coverages of traffic. The cracking did not appear to affect the load-carrying capacity of the pavement but was considered severe enough to have caused cracking in an asphaltic concrete surfacing. Therefore, the item was rated as border line. Items 1, 2, 3, and 4 at the end of 7186 coverages are shown in photographs 12 through 15, respectively.

32. Plots of coverages versus deformation for items 1, 2, 3, and 4 are shown in plates 5 and 6. These data indicate that the elastic deflections at top of subbase and subgrade in items 1, 2, and 3 were of about the same magnitude as were measured during phase 2 traffic. This was true in spite of the fact that the total thickness over subgrade was 3 in. less than that which existed during phase 2 traffic. The cumulative permanent deformation during phase 3 traffic was considerably less in all four items than that which occurred during phase 1 and phase 2 traffic. This, along with the elastic deflection data and visual observation of behavior, indicated that the pavement structure was actually gaining strength with load traffic; therefore, traffic-testing was discontinued. In-place CBR data obtained at end of phase 3 traffic (table 1) verified the fact that there

was an increase in strength in all items at the end of phase 3 traffic over that which existed at end of phase 2 traffic.

Summary of Test Results

Deflection and deformation data

33. A summary of the elastic deflection data and permanent deformation as measured during the three phases of traffic is shown in table 2. The table includes the maximum elastic deflection measured at the various elevations during each phase of traffic, the permanent deformation or settlement which occurred during each phase of traffic, and the total cumulative permanent deformation resulting from all three phases of traffic. From these data it can be noted that for items 1, 2, and 3 the elastic deflection was least in item 1 (the thickest item) for all phases of traffic and greatest in item 3 (the thinnest item). The greatest deflection measured in any of the test items was 0.22 in. in test item 3. The total permanent deformation or settlement was about the same in all three items, varying from 1.12 to 1.20 in. This is a relatively small amount of settlement considering the severity of traffic applied. The total settlement indicated in test item 4 was 2.52 in. This value represents the average settlement across the total width of traffic lane. Somewhat greater settlement occurred near the center of traffic lane.

Settlement plate data, item 4

34. Plots of settlement versus depth for the sand subgrade (item 4) at the end of each phase of traffic are shown in plate 7. These data, obtained from the settlement plates installed during construction, indicate a total settlement of about 3 in. at top of sand subgrade. As can be noted, the greatest amount of settlement occurred during phase 1 traffic and the least amount during phase 3. The indicated settlement near bottom of sand subgrade may be partially due to a loss of sand into the limestone drainage blanket.

Density and CBR data, item 4

35. At the end of phase 3 traffic, a test pit was excavated in item 4 for the full depth of the sand subgrade, and water-content and density determinations were made at 6-in. increments of depth for comparison

with the as-constructed values. In-place CBR determinations were also made from the surface to a depth of 30 in. into the sand subgrade. These data together with the as-constructed values are shown in table 3. These data indicate that densification occurred to a depth of 75 in. below the pavement surface or 60 in. from top of sand subgrade. There is little or no evidence of an increase in density below the 60-in. depth. The high CBR value of 117 developed at the surface of the sand subgrade illustrates the high potential strength of a sand when confined and highly densified. The CBR values below the surface are not considered very reliable due to the loss of confinement and the disturbance caused in excavating the test pit.

PART IV: ANALYSIS AND DISCUSSION OF DATA

Total Thickness Study

36. The primary objective of this study was to determine whether the increase in total thickness above subgrade as included in the interim design criteria for channelized traffic issued in June 1955 is needed. Flexible pavement design curves for a twin-assembly bicycle gear are shown in plate 8. The two solid-line curves represent the design criteria for 100,000- and 150,000-lb twin-assembly loads that were in effect prior to June 1955. The broken-line curves represent the interim design criteria as issued in June 1955 and are essentially the same as currently specified in fig. 11 of EM 1110-45-302.

37. The points plotted in plate 8 represent the total thickness and subgrade CBR of the three test items utilized in this study. The different symbols correspond to the total thickness and subgrade CBR of the various items at the start of each phase of traffic. As previously reported, test items 1 and 2 performed satisfactorily throughout all three phases of traffic. Item 3 performed satisfactorily during phases 1 and 2 traffic but was considered a borderline case during phase 3 traffic. The total thickness of item 3 during phase 3 traffic was only 25 in. or 61 percent of the current design thickness for a 150,000-lb twin-wheel load and only 78 percent of the thickness which would have been required prior to June 1955. Item 2, which showed no distress during traffic, was only 82 percent as thick as required by the interim design criteria and only 1 in. in excess of the thickness which would have been required prior to June 1955. These data indicate that the original thickness design criteria in effect prior to June 1955 were adequate and that the increase in total thickness was not needed.

38. The thickness design for all Corps of Engineers flexible pavement design curves is based on a relation of percentage of design thickness to coverages. The basic plot showing this relation is included as inclosure 2 to a letter from WES to Office, Chief of Engineers, subject: "Design Curves for Less than Capacity Operations," dated

18 April 1949.* This basic curve shows that an increased thickness is required for an increase in load repetitions or traffic coverages up to 5000 coverages, which is considered as 100 percent of design thickness for capacity operation. The increased thickness included in the interim design criteria for channelized traffic was based on an extrapolation of this basic curve from 5000 to 25,000 coverages. The relation of thickness versus coverages up to 5000 coverages has been fairly well validated in the field. However, the results of tests reported herein indicate that the extrapolation to 25,000 coverages may not be valid. For the test reported herein, the maximum elastic deflection under each phase of traffic was measured at less than 2000 coverages of traffic. These data together with visual observations of behavior and in-place CBR determinations indicated that an increase in coverages beyond about 2000 coverages was actually beneficial, resulting in an overall increase in strength and load-carrying capacity of the pavement structure. The increased coverages did result in an increase in permanent deformation or settlement due to densification of the base and subbase material, which indicates that bases and subbase courses should be compacted to the highest practicable density during construction, especially for channelized traffic areas.

39. It is pointed out that the test reported herein checks only one point on the CBR design curves, that for a subgrade with a CBR in the range of 11 to 14. Therefore, it is considered desirable that additional tests be made for both a lower strength and higher strength subgrade before any drastic changes are made in the current thickness design criteria. First priority should be given to a study of a low-strength subgrade with CBR in the order of 3 to 5 (the range where the greatest thicknesses are required).

Compaction Study

40. The data from test item 4 (deep sand subgrade) were obtained to validate the revised compaction requirements for cohesionless subgrade materials. Plots of density in percentage of modified AASHO maximum versus depth, as shown in plate 9, indicate the as-constructed density and density

* See also Collection of Letter Reports on Flexible Pavement Design Curves, Waterways Experiment Station, Vicksburg, Miss., June 1951.

after traffic. Also shown are the (revised) current compaction requirements for cohesionless materials to be subjected to channelized traffic of a 150,000-lb twin-assembly load. In the design of the test section, it was assumed that the degree of compaction developed by the accelerated traffic would indicate the proper compaction requirements. The data shown in plate 9 reveal that traffic resulted in an increase in density to a depth of about 76 in. in the sand subgrade, and that the final density after traffic exceeded the current compaction requirements (before proof-rolling) for cohesionless materials to a depth of 48 in. The final density below the 48-in. depth is in fair agreement with current compaction requirements. It can also be seen from table 1 that densities in the order of 105 to 108 percent of modified AASHO maximum were developed in the limestone base and the sand-gravel subbase materials (both cohesionless materials) in test items 1, 2, and 3 as a result of proof-rolling. This is about the same percentage of modified density that was developed by test traffic in the sand subgrade to a depth of 36 in. below the surface of the pavement, which indicates that the compaction requirements for sands should be about the same as those for any other cohesionless materials.

41. The data discussed above indicate that in order to avoid any settlement in a flexible pavement structure from channelized traffic of heavy aircraft, the top 3 ft of all cohesionless materials should be compacted to a minimum of 105 percent of modified AASHO maximum density. Below the 3-ft depth the current compaction requirements appear to be adequate. As shown in plate 9, the current compaction requirements for cohesionless materials for a 150,000-lb twin-assembly load are a minimum of 100 percent of modified AASHO maximum density to a depth of 4 ft. Proof-rolling is required at a depth of 16 in. and on each layer above this depth. Although 100 percent modified AASHO maximum density is all that is actually required, the intent of the specification is to obtain the maximum density possible with a reasonable compaction effort, but in no case less than 100 percent. For some cohesionless materials, such as the limestone base used in this study, 105 percent of modified AASHO maximum density can be obtained during construction with a reasonable compaction effort. However, it would be very difficult to compact a clean sand similar to that used in this study to 105 percent of modified density with currently

available compaction equipment. Therefore, the current compaction requirements plus proof-rolling are considered reasonable and about the maximum that can be assured in the field at the present time.

42. The high strength developed in the sand subgrade due to densification under traffic, as discussed in paragraph 35, warrants continued research in the development of equipment, methods, and procedures for compacting cohesionless materials to higher densities than are now practicable.

PART V: CONCLUSIONS AND RECOMMENDATIONS

43. Based on the data presented in this report, the following conclusions appear warranted:

a. The increase in total thickness for channelized traffic areas as specified in the interim design criteria published in June 1955 is not needed.

b. Current compaction requirements for cohesionless soils used in channelized traffic areas are adequate for cohesionless subgrades for depths below about 3 ft from surface of pavement. Any cohesionless materials (base, subbase, or subgrade) above the 3-ft depth should be compacted to the highest practicable density.

44. Based on the data presented in this report, the following recommendations appear warranted:

a. As pointed out in paragraph 39, the data reported herein check only one point on the CBR design curves, that for a subgrade with CBR in the range of 11 to 14. Therefore, it is recommended that additional tests be made of a lower strength subgrade (CBR of about 3 to 5) and a higher strength subgrade (CBR of about 20) before any changes are made in the current design curves.

b. All data possible should be collected from airfield condition surveys, pavement evaluations, etc., and utilized to validate or modify the basic curve showing the relation of percentage of design thickness to coverages, as discussed in paragraph 38.

c. Research in soil compaction should be continued to develop equipment, methods, and procedures for compacting cohesionless materials to higher densities than are now feasible. Higher densities are needed not only in pavement construction, but also in foundations of military installations located in similar materials.

Table 1

In-Place Water Content, Density, and CBR Determinations Before and After Traffic

Item No.	Material	Layer Thickness in.	Total Thickness in.	Twin-Wheel-Assembly Load, kips	Tire Pressure psi	Coverages	Water Content Per Cent	Dry Density lb/cu ft	Per Cent Modified AASHO	CBR
1	Limestone base	13	42	---	---	Before traffic	1.2	155.3	105	240*
		13	42	100	200	9,142	1.3	158.5	107	320*
		13	42	150	300	10,496	1.5	156.4	105	---
		10	39	150	300	7,186	1.3	157.7	106	378*
	Sand-gravel subbase	29	42	---	---	Before traffic	3.0	135.6	106	76
		29	42	100	200	9,142	2.9	133.4	106	107
		29	42	150	300	10,496	3.0	134.5	106	56
		29	39	150	300	7,186	2.6	135.5	106	80
	Fat clay subgrade	24	42	---	---	Before traffic	20.0	103.9	93	12
		24	42	100	200	9,142	21.2	103.9	93	13
		24	42	150	300	10,496	21.6	101.1	90	14
		24	39	150	300	7,186	21.7	104.7	93	13
2	Limestone base	13	35	---	---	Before traffic	1.8	156.6	105	300*
		13	35	100	200	9,142	1.7	159.1	107	500*
		13	35	150	300	10,496	1.5	159.1	107	---
		10	32	150	300	7,186	1.5	158.1	107	333*
	Sand-gravel subbase	22	35	---	---	Before traffic	3.3	133.3	106	57
		22	35	100	200	9,142	3.1	135.5	108	59
		22	35	150	300	10,496	3.2	135.0	108	55
		22	32	150	300	7,186	2.7	136.3	106	67
	Fat clay subgrade	24	35	---	---	Before traffic	20.4	101.8	91	11
		24	35	100	200	9,142	20.8	104.2	93	13
		24	35	150	300	10,496	21.7	102.3	91	13
		24	32	150	300	7,186	21.4	103.9	93	14
3	Limestone base	13	28	---	---	Before traffic	1.8	155.9	105	240*
		13	28	100	200	9,142	1.3	156.9	106	260*
		13	28	150	300	2,758	1.4	158.3	107	277*
		13	28	150	300	10,496	1.5	158.1	107	---
		10	25	150	300	7,186	1.2	158.7	107	433
	Sand-gravel subbase	15	28	---	---	Before traffic	3.1	137.0	109	62
		15	28	100	200	9,142	3.3	136.3	109	63
		15	28	150	300	2,758	2.9	134.6	107	41
		15	28	150	300	10,496	3.3	135.3	108	68
		15	25	150	300	7,186	2.6	137.1	107	97
	Fat clay subgrade	24	28	---	---	Before traffic	19.8	102.1	91	11
		24	28	100	200	9,142	20.9	105.0	94	12
		24	28	150	300	2,758	21.9	101.6	91	12
		24	28	150	300	10,496	21.6	97.2	87	12
		24	25	150	300	7,186	21.1	105.0	94	14
4	Limestone base	15	15	---	---	Before traffic	1.6	156.4	105	200*
		15	15	100	200	9,142	1.3	158.2	107	500*
		15	15	150	300	10,496	---	---	---	---
		15	15	150	300	7,186	1.2	157.4	---	---
	Top of sand subgrade	96	15	---	---	Before traffic	3.6	104.4	99	38
		96	15	100	200	9,142	3.0	104.9	100	56
		96	15	150	300	10,496	---	---	---	---
		96	15	150	300	7,186	1.3	112.7	107	117

* CBR values were obtained by extrapolation from readings at less than 0.1-in. penetration.

Table 2

Summary of Deflection and Deformation Data

Item No.	Location of Measurement	Traffic Phase 1 Maximum Deflection in.	Traffic Phase 1 Permanent Deformation in.	Traffic Phase 2 Maximum Deflection in.	Traffic Phase 2 Permanent Deformation in.	Traffic Phase 1 and 2 Cumulative Deformation in.	Traffic Phase 3 Maximum Deflection in.	Traffic Phase 3 Permanent Deformation in.	Traffic Phase 1, 2, and 3 Cumulative Deformation in.
1	Top of subgrade	0.06	0.04	0.11	0.12	0.16	0.10	0.13	0.29
	Top of subbase	0.09	0.20	0.14	0.30	0.50	0.13	0.20	0.70
	Surface of pavement	--	0.48	--	0.45	0.93	0.13	0.22	1.15
2	Top of subgrade	0.08	0.05	0.16	0.13	0.18	0.14	0.11	0.29
	Top of subbase	0.13	0.26	0.19	0.40	0.66	*	0.15**	0.81
	Surface of pavement	--	0.50	--	0.40	0.90	0.16	0.22	1.12
3	Top of subgrade	0.11	0.08	*	*	*	0.18	†	--
	Top of subbase	0.14	0.30	0.22	0.36	0.66	0.20	0.15	0.81
	Surface of pavement	--	0.58	--	0.40	0.98	0.22	0.22	1.20
4	Surface of pavement	--	1.19	--	1.00	2.19	--	0.33	2.52

* Deflection gage out of order.

** Estimated, gage out of order at 740 coverages.

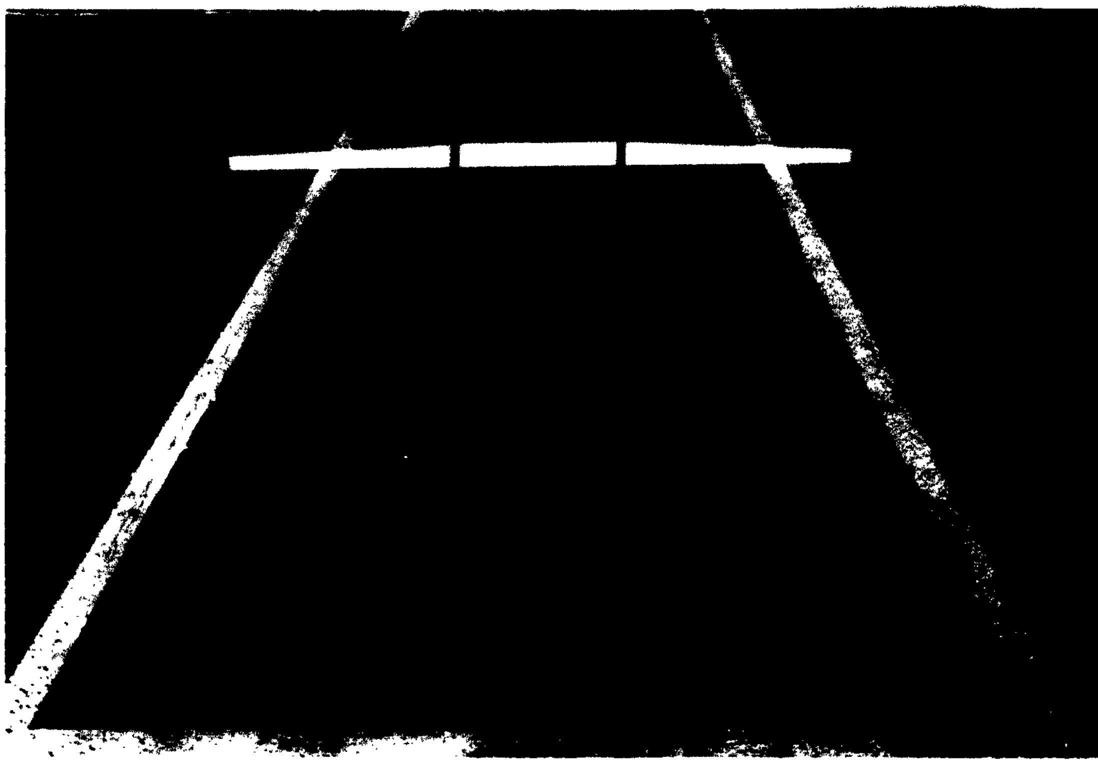
† Gage out of order at 40 coverages.

Table 3

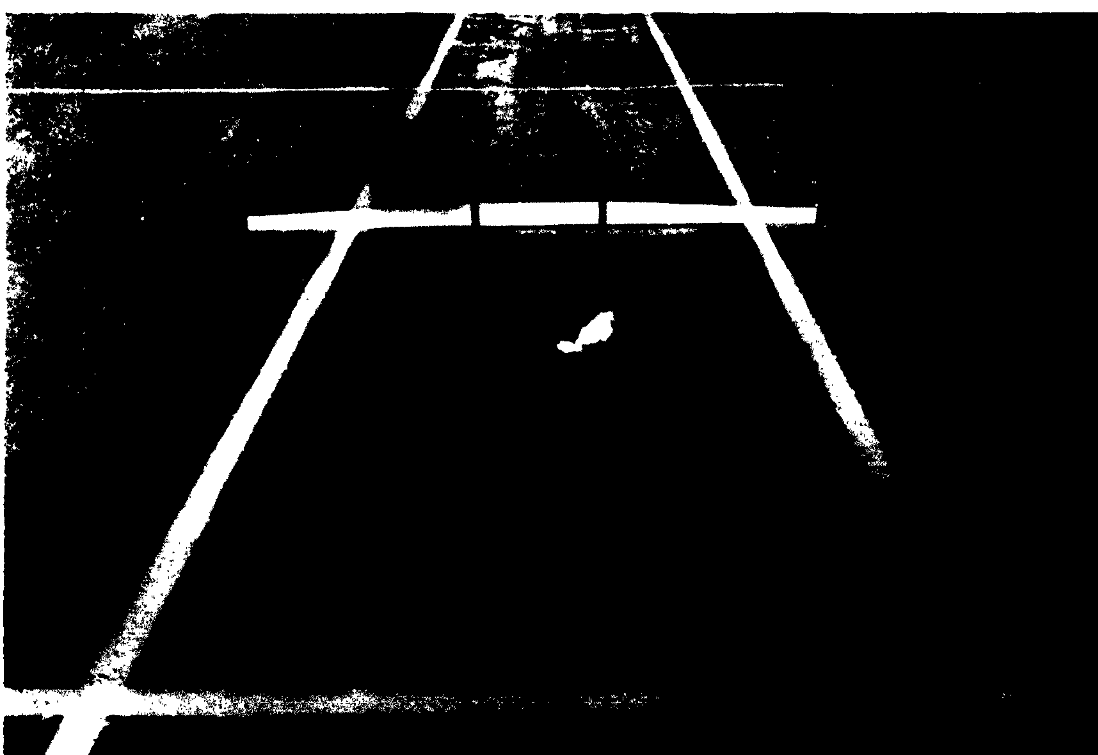
Summary of In-Place CBR, Water Content, and Density Data

Sand Subgrade, Item 4

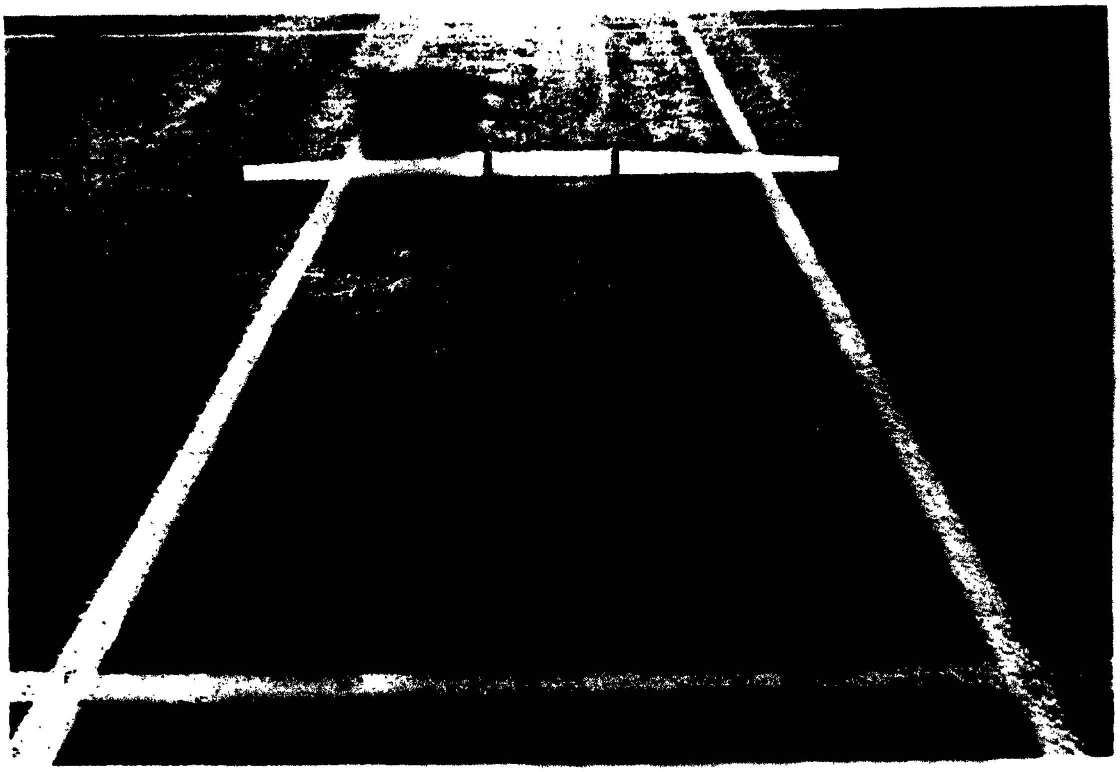
Depth from Surface of Pavement in.	Depth from Surface of Sand Subgrade in.	As Constructed				At End of Phase 3 Traffic			
		CBR	Water Content Per Cent	Dry Density lb/cu ft	Density in Per Cent of Mod AASHO Max	CBR	Water Content Per Cent	Dry Density lb/cu ft	Density in Per Cent of Mod AASHO Max
15	0	38	0.3	104.4	99.3	117	1.3	112.7	106.8
21	6		0.1	104.8	99.7	54	1.6	112.7	106.8
27	12		0.2	105.0	99.8	28	1.7	112.4	106.5
33	18		0.2	106.1	100.8	22	2.2	110.9	105.1
39	24		3.1	92.6	88.0	20	1.1	108.9	103.2
45	30		---	---	---	13	2.4	104.1	98.7
51	36		3.4	92.2	87.6	---	2.6	101.9	96.6
57	42		---	---	---	---	3.7	102.0	96.7
63	48		2.8	94.0	89.4	---	2.5	99.3	94.1
69	54		---	---	---	---	2.6	97.3	92.2
75	60		2.9	95.2	90.5	---	2.6	96.1	91.1
81	66		---	---	---	---	2.5	95.4	90.4
87	72		3.0	95.9	91.1	---	3.0	94.9	90.0
93	78		---	---	---	---	2.5	96.7	91.7
99	84		2.9	94.0	89.4	---	2.3	96.3	91.3



Photograph 1. Item 1 at the end of phase 1 traffic



Photograph 2. Item 2 at the end of phase 1 traffic

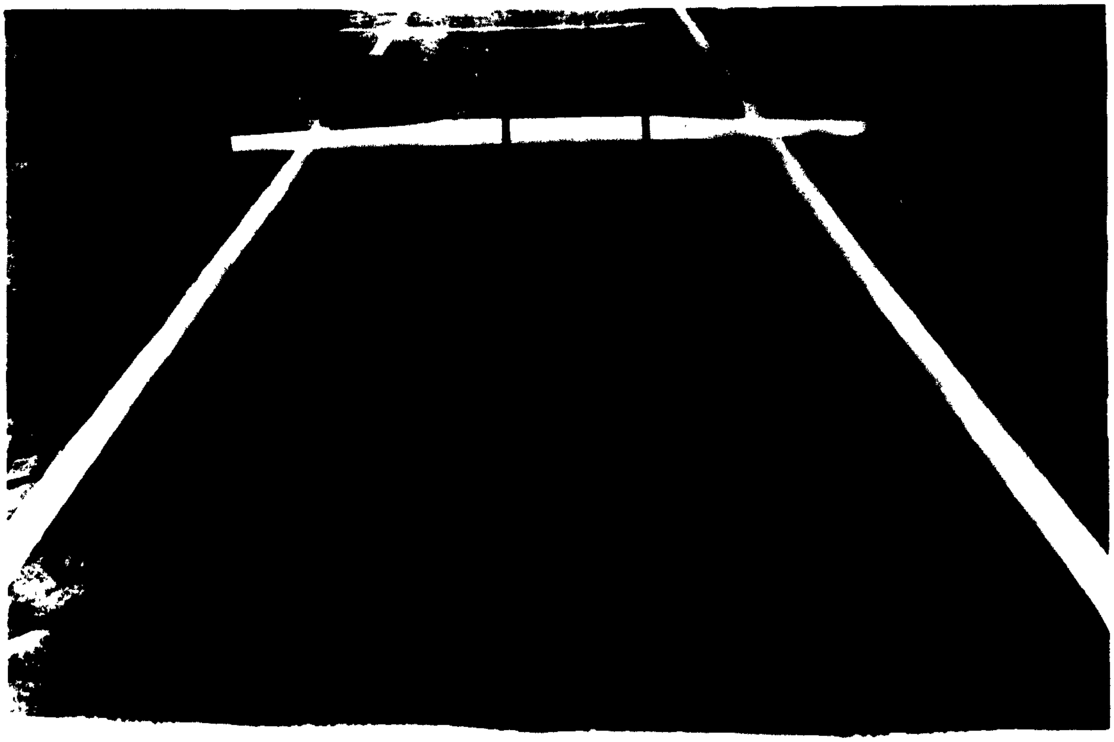


Photograph 3. Item 3 at the end of phase 1 traffic

Photograph 4. Item 4 at the end of phase 1 traffic

Photograph 5. Crack in item 3 at the end of 4000 coverages of phase 2 traffic

Photograph 6. Crack in item 4, 18 in. outside traffic lane after 4000 coverages of phase 2 traffic



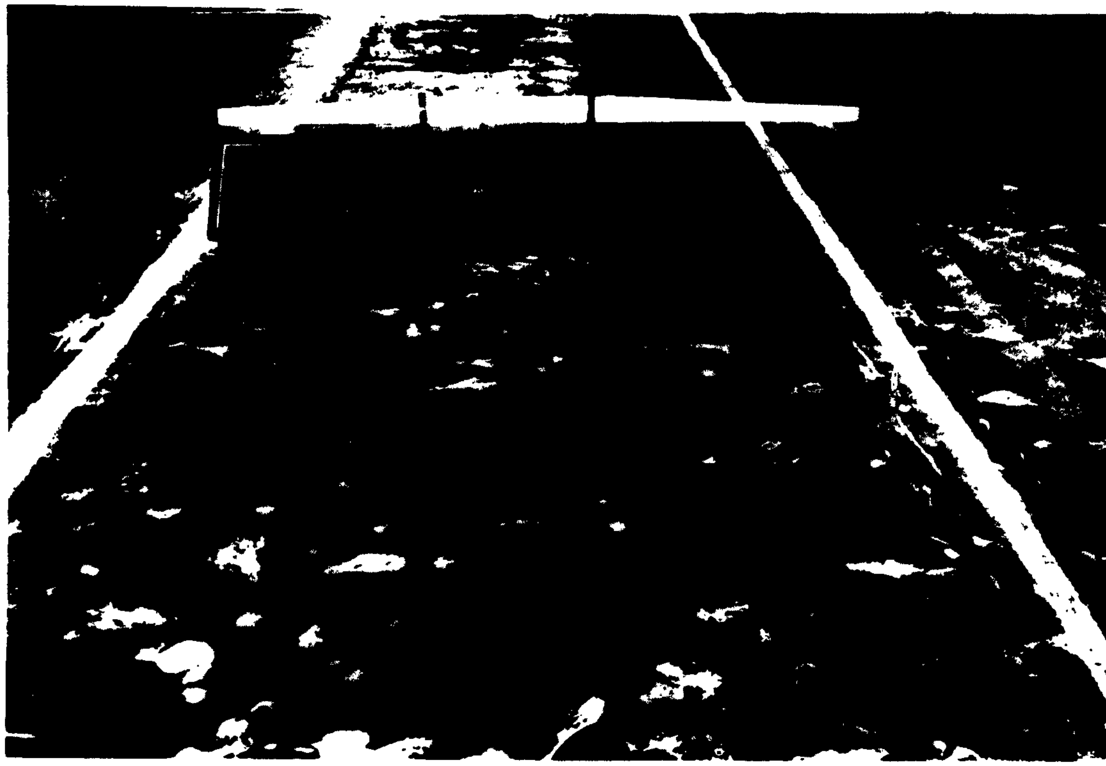
Photograph 7. Item 1 at the end of phase 2 traffic

Photograph 8. Item 2 at the end of phase 2 traffic

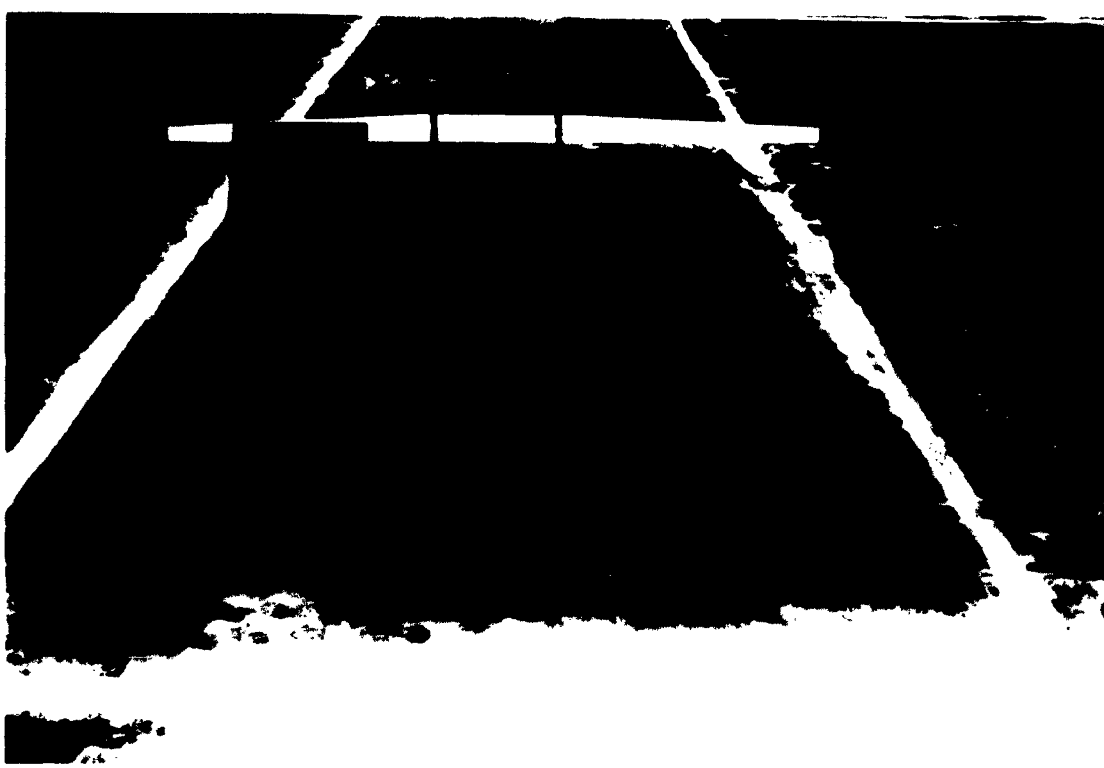
Photograph 9. Item 3 at the end of phase 2 traffic

Photograph 10. Item 4 at the end of phase 2 traffic

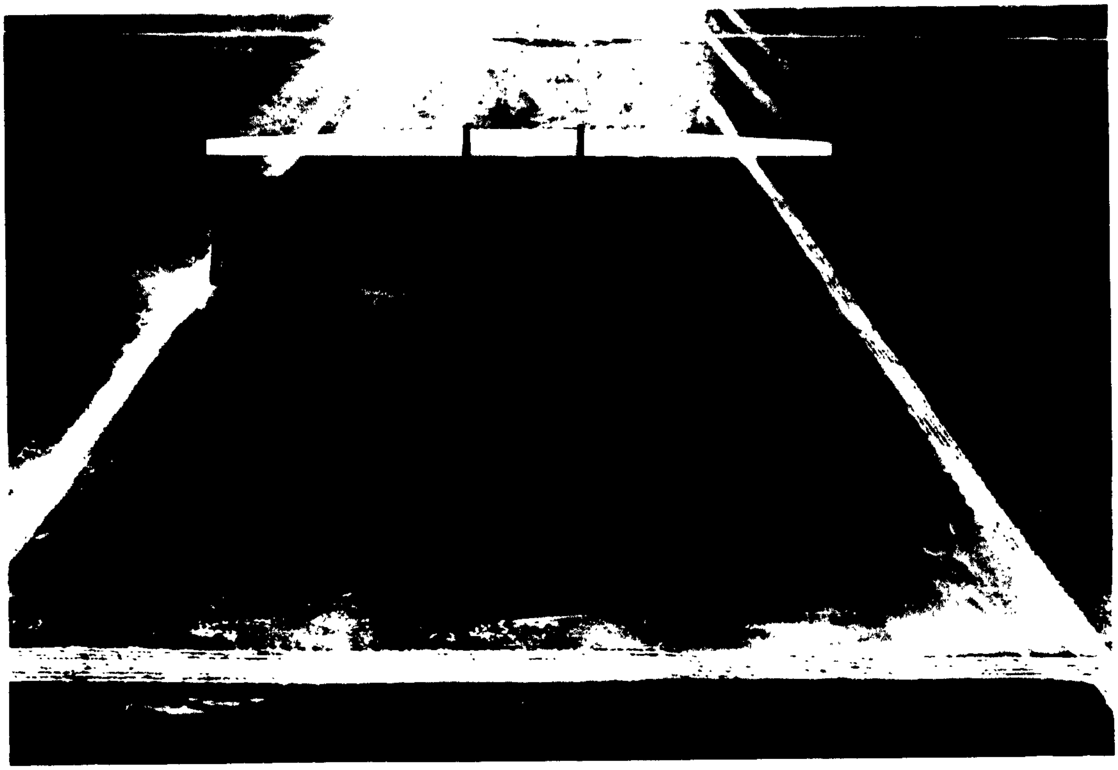
Photograph 11. Crack in item 3 at the end of 5743 coverages of phase 3 traffic



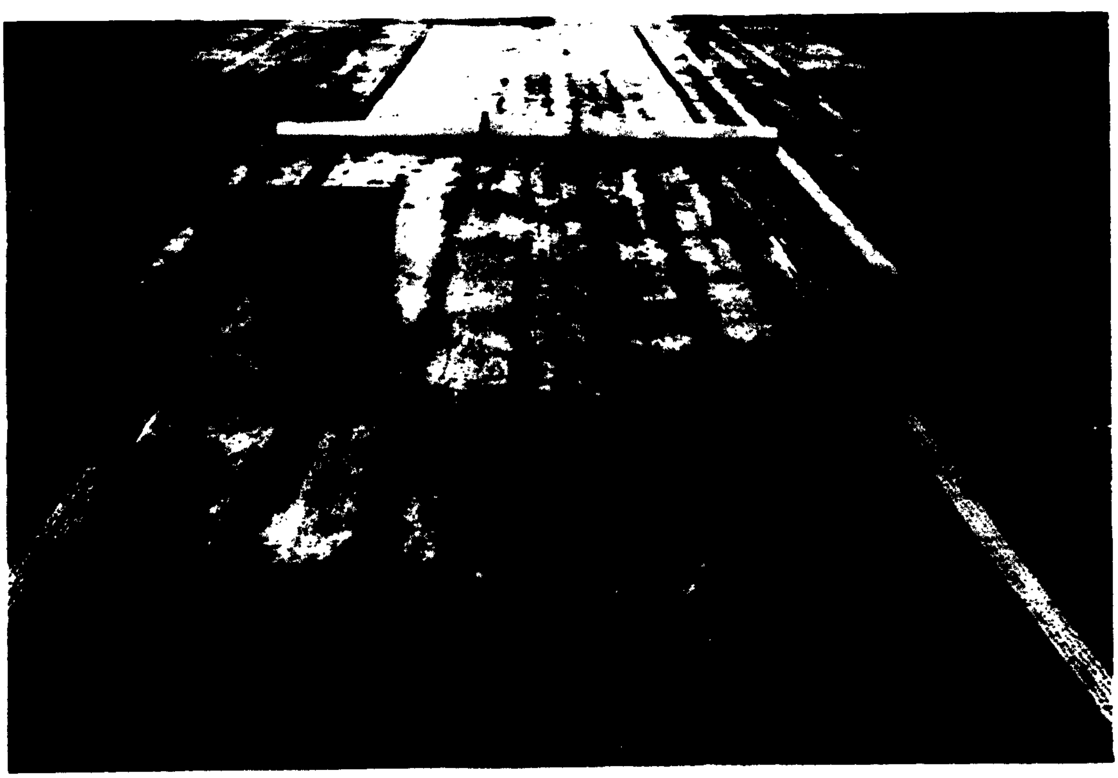
Photograph 12. Item 1 at the end of phase 3 traffic



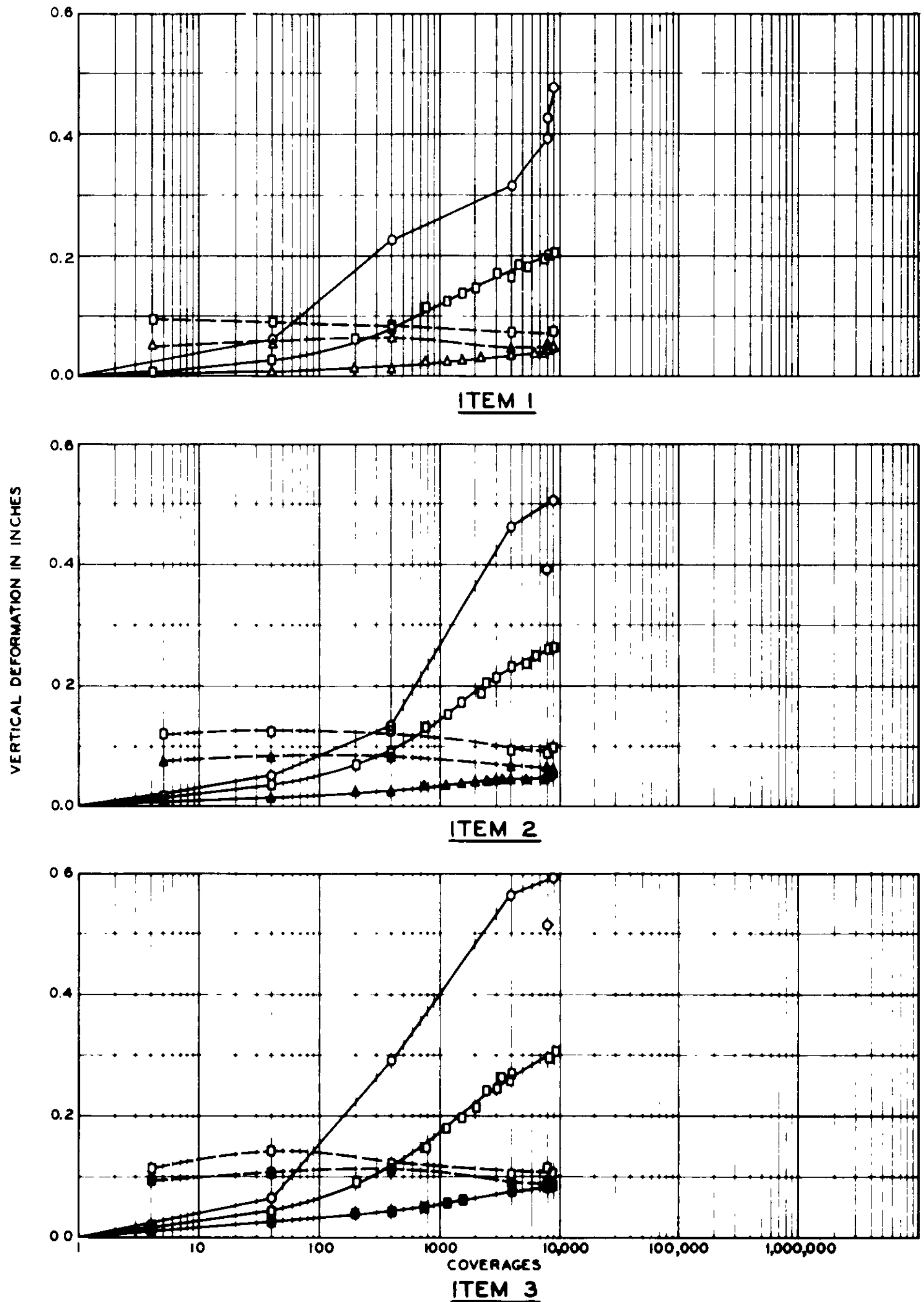
Photograph 13. Item 2 at the end of phase 3 traffic



Photograph 14. Item 3 at the end of phase 3 traffic



Photograph 15. Item 4 at the end of phase 3 traffic

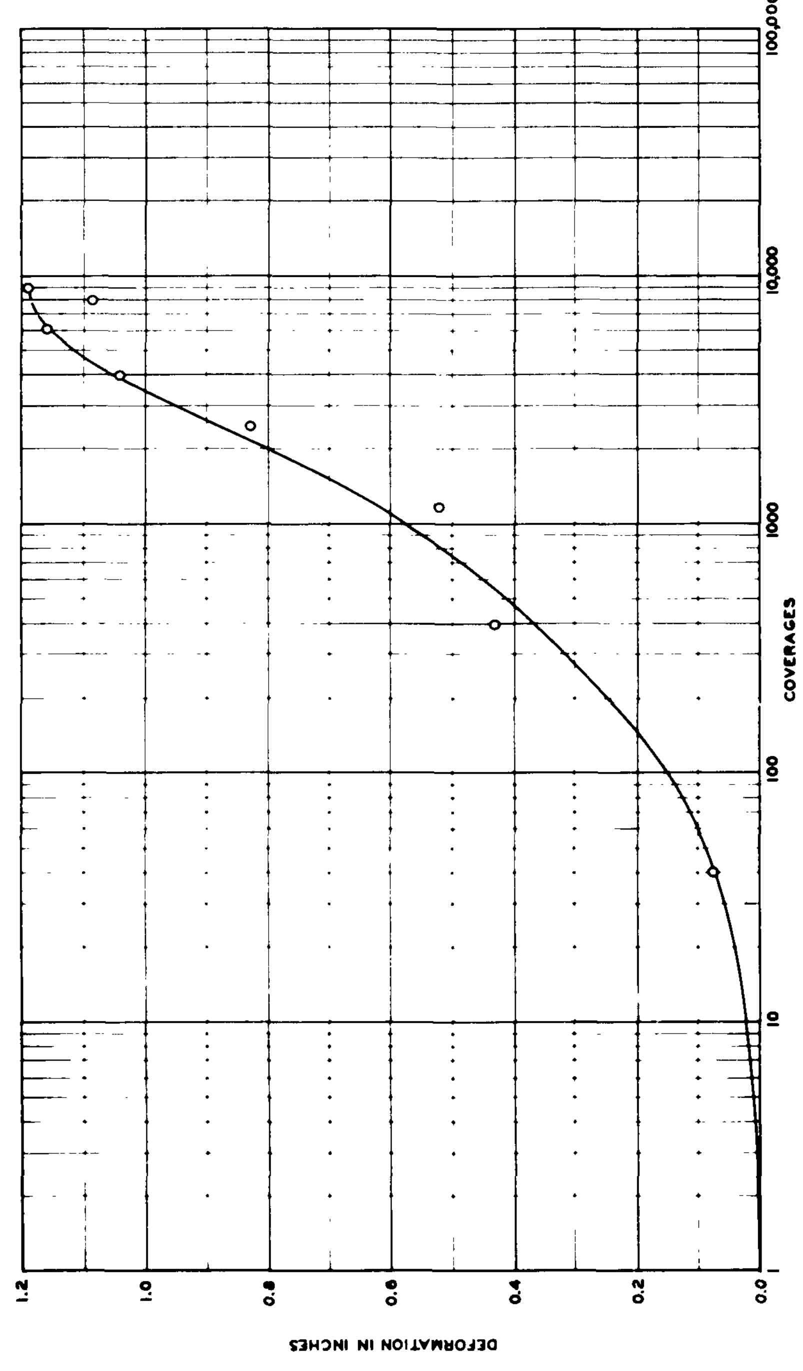


LEGEND

- ○ SURFACE
- □ 13-IN. DEPTH (SURFACE OF SUBBASE)
- ■ 28-IN. DEPTH (SURFACE OF SUBGRADE)
- ▲ 35-IN. DEPTH (SURFACE OF SUBGRADE)
- △ 42-IN. DEPTH (SURFACE OF SUBGRADE)
- ——— PERMANENT DEFORMATION
- — — — DEFLECTION (RIGHT TIRE OF TWIN-WHEEL ASSEMBLY DIRECTLY OVER GAGE)

DEFORMATION AND DEFLECTION

ITEMS 1, 2, AND 3
PHASE 1 TRAFFIC

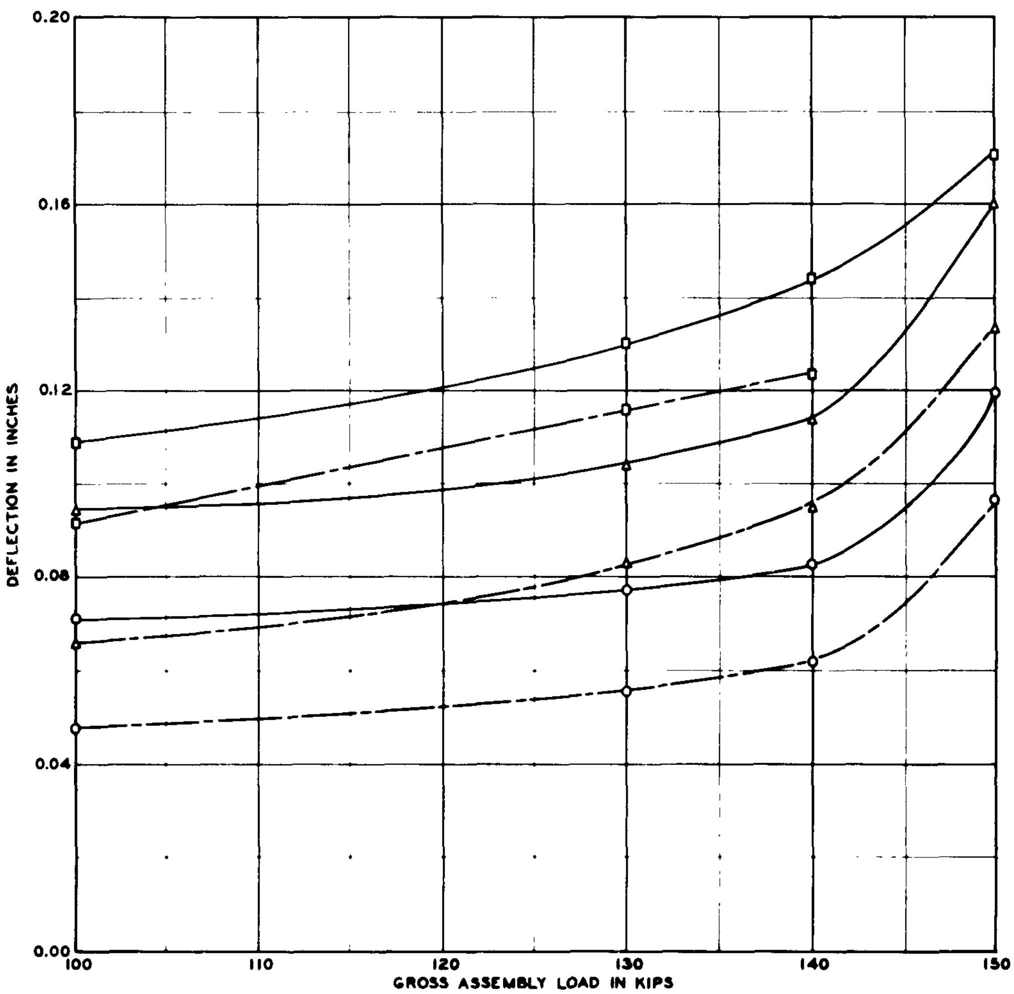


NOTE: DEFORMATION IS THE AVERAGE FOR THE 7.3-FT WIDE TRAFFIC LANE AT STATIONS 1+05 AND 1+15.

SURFACE DEFORMATION OF ITEM 4

DURING PHASE I TRAFFIC

PLATE 2



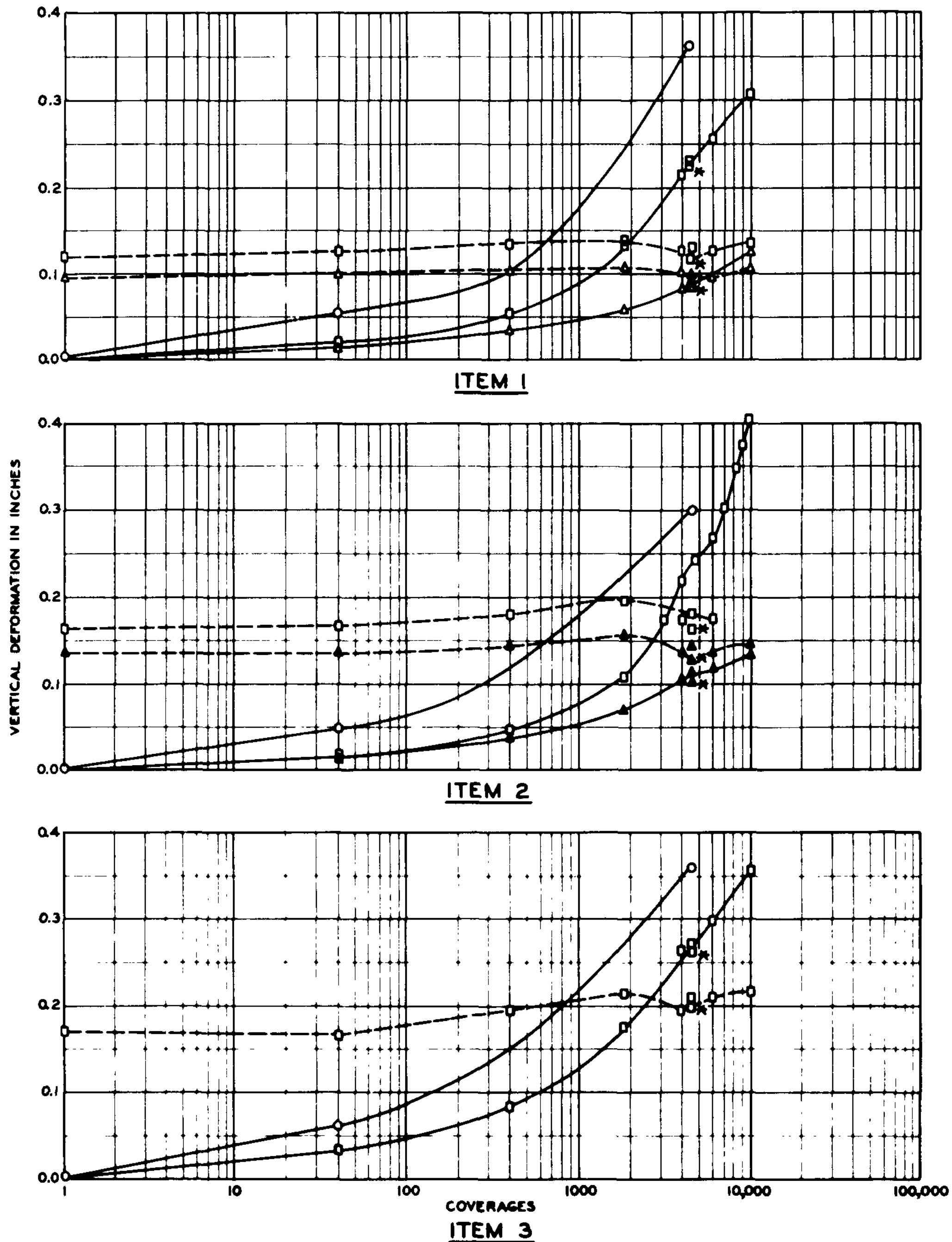
LEGEND

- O ITEM 1
- Δ ITEM 2
- □ ITEM 3
- ——— SURFACE OF SUBBASE
- — - — SURFACE OF SUBGRADE

NOTE: NO DEFLECTION DATA AVAILABLE FOR SUBGRADE ITEM 3 AT 150-KIP LOAD.

DEFLECTIONS UNDER A RANGE OF LOADS

ITEMS 1-3

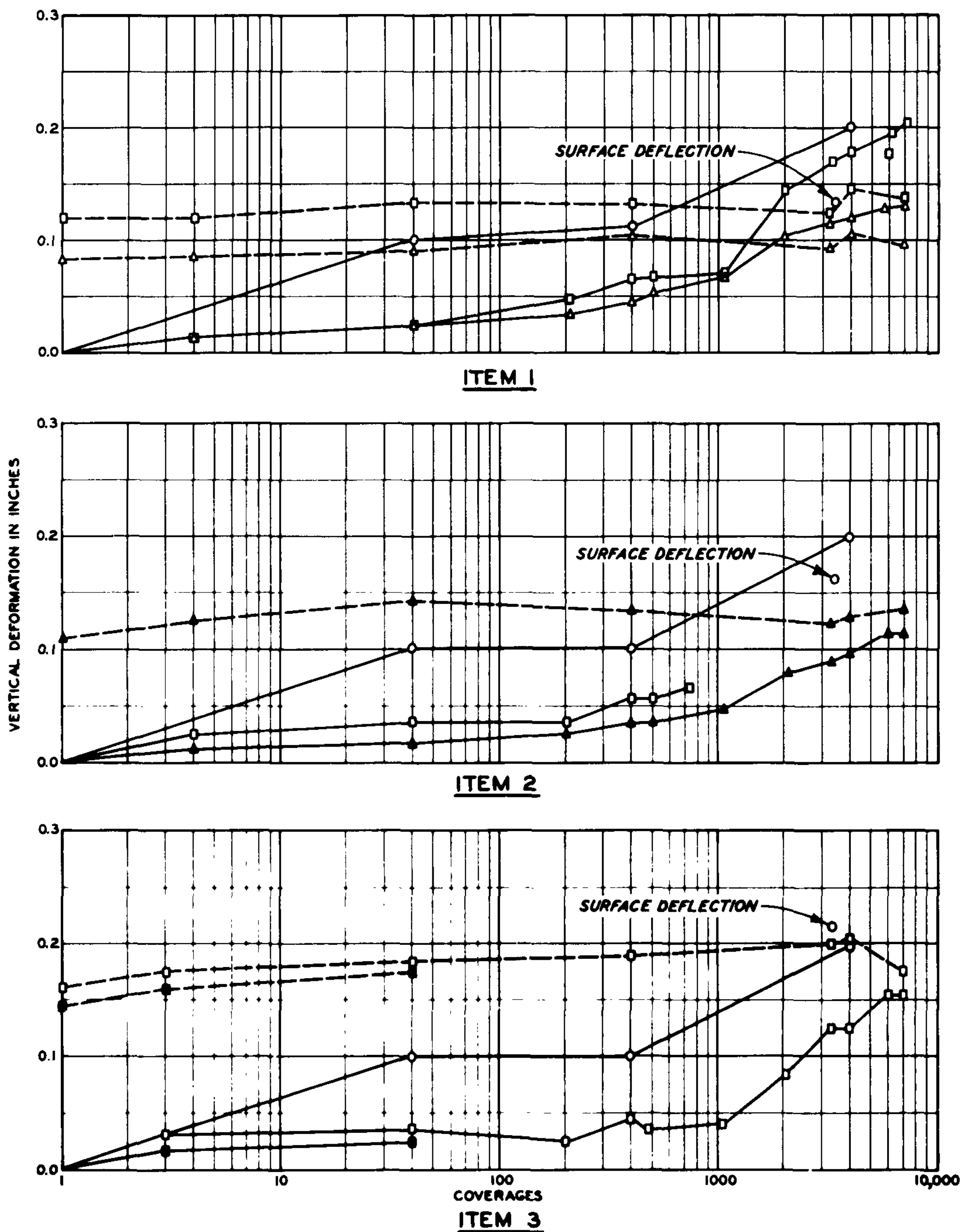


LEGEND

- O SURFACE
- □ 13-IN. DEPTH (SURFACE OF SUBBASE)
- ▲ 35-IN. DEPTH (SURFACE OF SUBGRADE)
- △ 42-IN. DEPTH (SURFACE OF SUBGRADE)
- ——— PERMANENT DEFORMATION
- – – – DEFLECTION

NOTE: * AFTER SAND-ASPHALT SURFACE COURSE.
GAGE AT 28-IN. DEPTH (SURFACE OF SUBGRADE, ITEM 3) OUT OF ORDER.

DEFORMATION AND DEFLECTION
ITEMS 1, 2, AND 3
PHASE 2 TRAFFIC

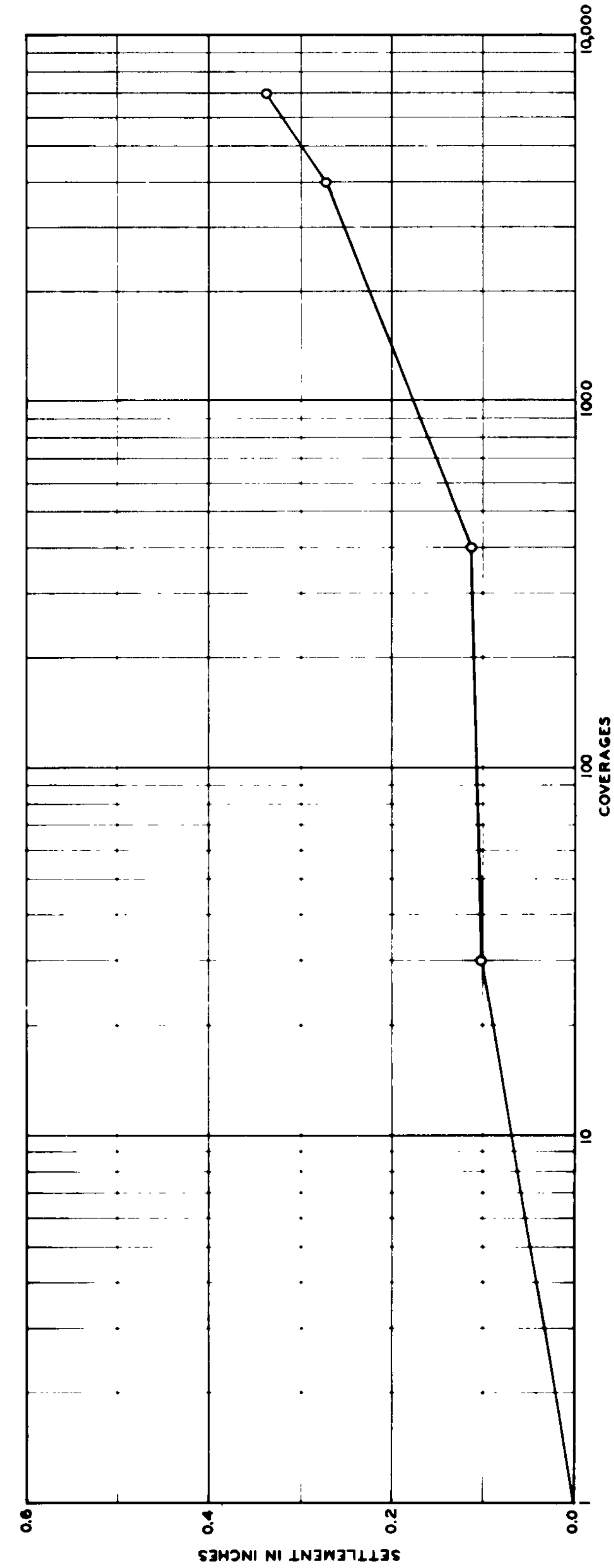


LEGEND

- O SURFACE
- □ 10-IN. DEPTH (SURFACE OF SUBBASE - ITEM 2 GAGE OUT OF ORDER AT 740 COVERAGES)
- ■ 25-IN. DEPTH (SURFACE OF SUBGRADE - ITEM 3 GAGE OUT OF ORDER AT 40 COVERAGES)
- ▲ 32-IN. DEPTH (SURFACE OF SUBGRADE)
- △ 39-IN. DEPTH (SURFACE OF SUBGRADE)
- ——— PERMANENT DEFORMATION
- – – – DEFLECTION (RIGHT TIRE OF TWIN-WHEEL ASSEMBLY DIRECTLY OVER GAGE)

DEFORMATION AND DEFLECTION

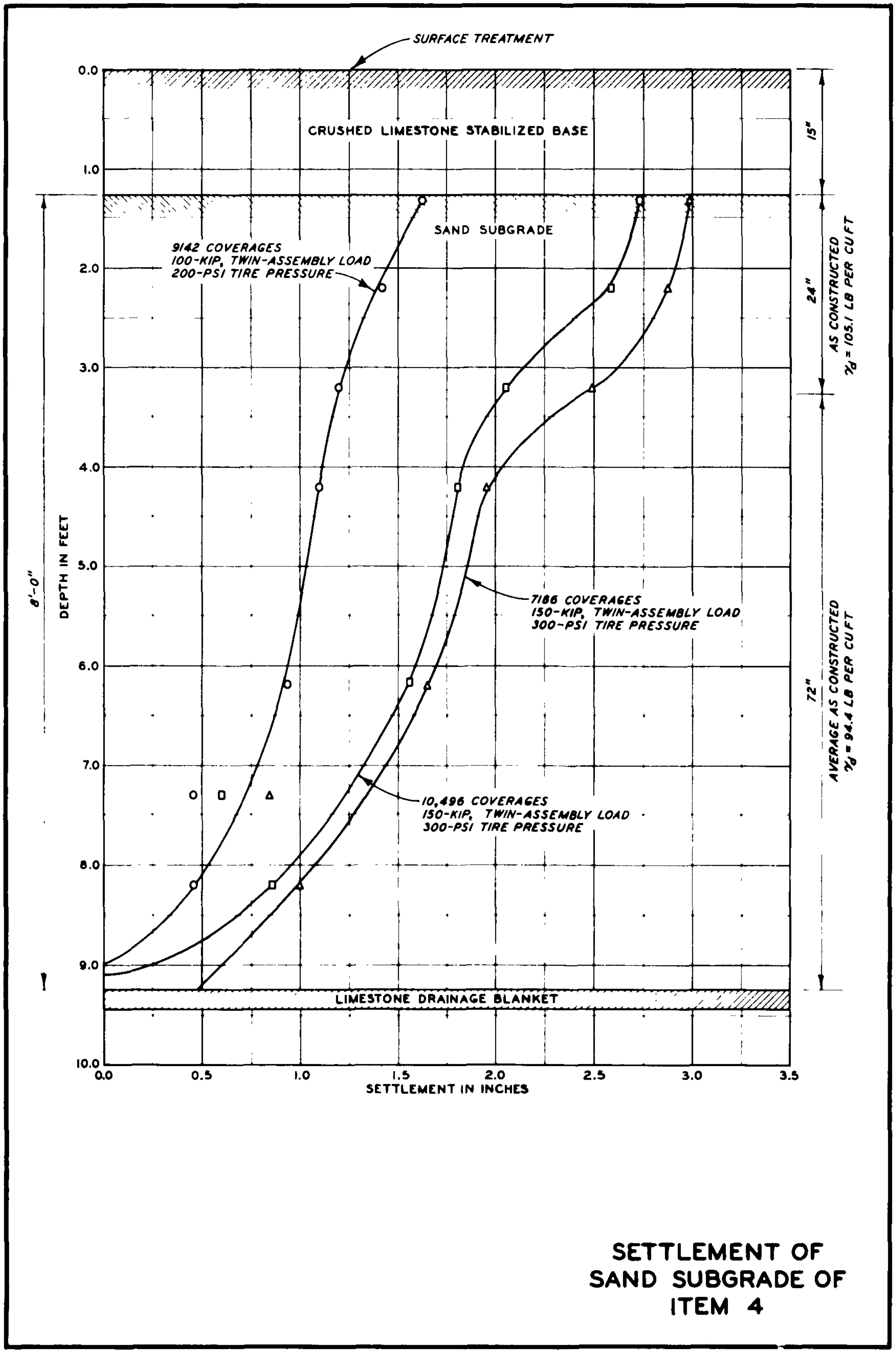
ITEMS 1, 2, AND 3
PHASE 3 TRAFFIC



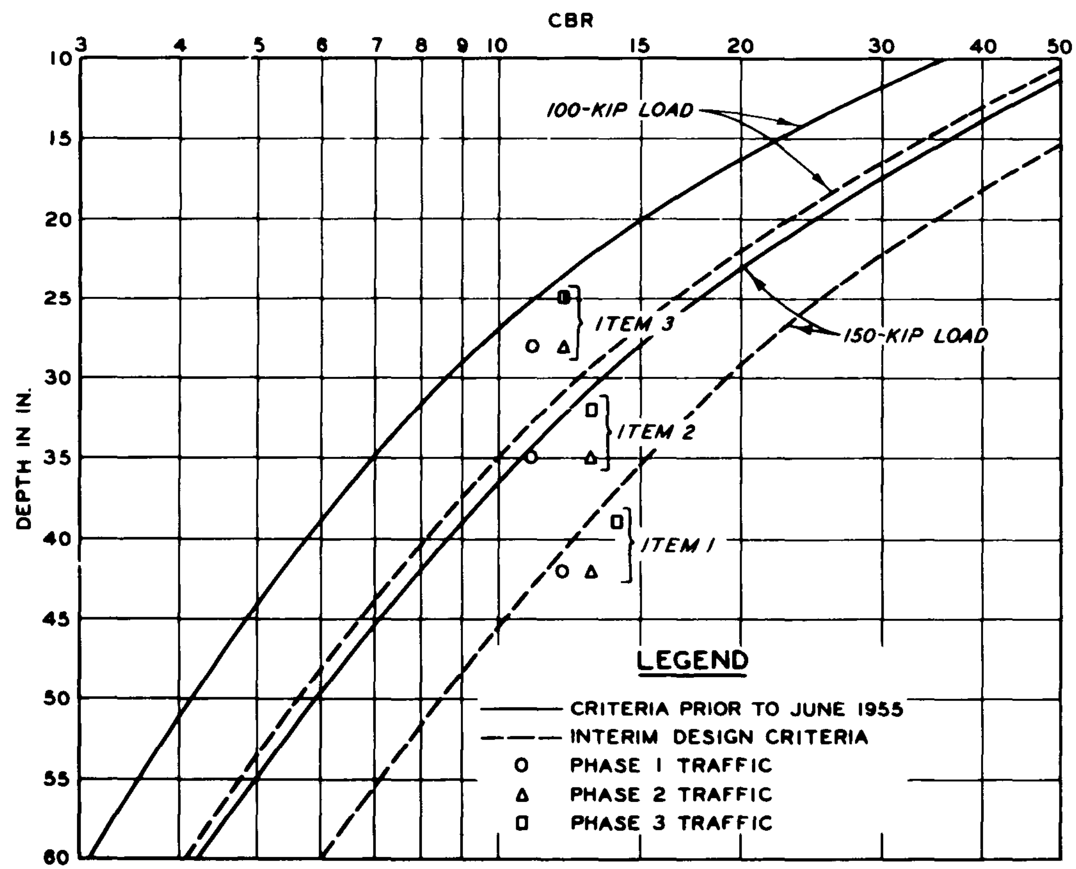
SURFACE SETTLEMENT OF ITEM 4

DURING PHASE 3 TRAFFIC

050857-H

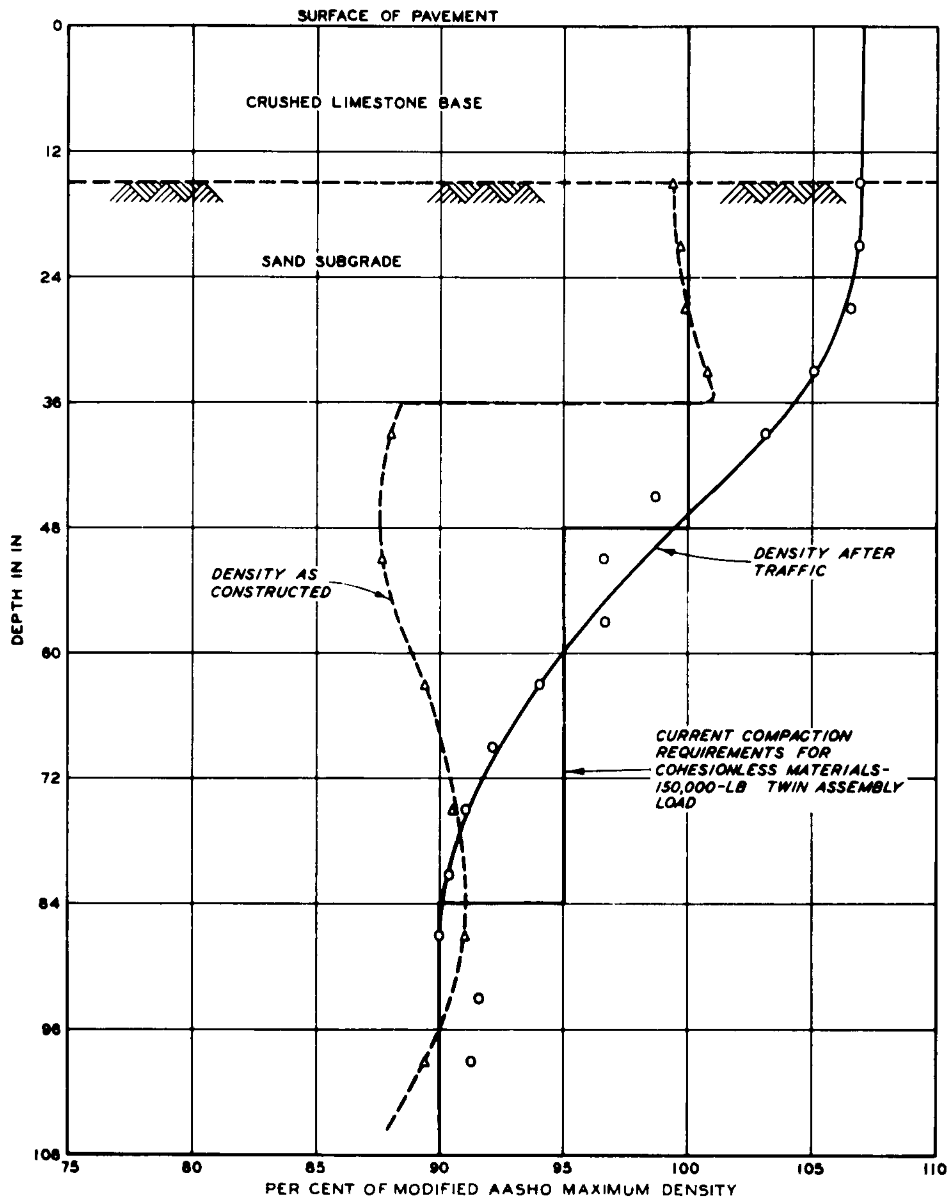


SETTLEMENT OF SAND SUBGRADE OF ITEM 4



NOTE: OPEN SYMBOL, SATISFACTORY PERFORMANCE.
HALF-CLOSED SYMBOL, BORDERLINE CONDITION.

FLEXIBLE PAVEMENT DESIGN CURVES
TWIN ASSEMBLY, BICYCLE GEAR
SPACING, 37 IN.
CONTACT AREA, 267 SQ. IN. EACH WHEEL



DENSITY DATA

COMPACTION STUDY, ITEM 4